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TECHNICAL REPORT

"Sea Force"
A Sea Basing Platform

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13. ABSTRACT *(maximum 200 words)*

The need for effective operation from the sea while conducting amphibious operations ashore has never been more evident than in today's modern conflicts. As important as this task is it has not been significantly changed since World War I. Sea Force is an attempt to show how that sea basing, as discussed by the CNO in Sea Power 21, can be accomplished by the year 2020 with reasonable advances in technology. The Total Ship Systems Engineering Program, under the tasking of CNO (N7) through the Wayne E. Meyer Institute of Systems Engineer, undertook the task of designing a system of ships that could be brought together to enable the sea basing of one Marine Expeditionary Brigade (MEB) for an indefinite period of time.

The Sea Force design completely supports all of the operational requirements of Ship to Objective Maneuver (STOM), in addition to providing a path for re-supply and method for reconstitution of forces ashore. Sea Force is also designed to be reconfigurable from a warship to a supply ship during a shipyard availability period with minimal effort through modularity.

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ABSTRACT

The need for effective operation from the sea while conducting amphibious operations ashore has never been more evident than in today's modern conflicts. As important as this task is it has not been significantly changed since World War I. "Sea Force" is an attempt to show how that sea basing, as discussed by the CNO in Sea Power 21, can be accomplished by the year 2020 with reasonable advances in technology. The Total Ship Systems Engineering Program, under the tasking of CNO (N7) through the Wayne E. Meyer Institute of Systems Engineer, undertook the task of designing a system of ships that could be brought together to enable the sea basing of one Marine Expeditionary Brigade (MEB) for an indefinite period of time.

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I. INTRODUCTION

This project is intended to support the Wayne Meyer Institute of Systems Engineering in developing the future notion of Marine Expeditionary Warfare in the year 2020 by designing a system of platforms that could be employed as a sea base. Under current operational concepts, the Marine Air-Ground Task Force (MAGTF) must establish a beachhead and then build up what has come to be known as the "Iron Mountain." The establishment of the beachhead has the potential to limit the options for the initial point of attack and allow the enemy to concentrate defenses at these points. Once the beachhead has been established all the equipment required to support the Ground Combat Element (GCE) is then brought ashore and staged for issue to the fighting units. During the operation each MAGTF is support by an Aviation Combat Element (ACE) that flies from large deck amphibious assault ships, and can eventually be transitioned to an air field in the vicinity of the objective for continued support. If no such air field exists, then the Combat Service Support Element (CSSE) has the ability to build a temporary air field, as well as medical and other support structures.

A MAGTF varies in size and configuration from a Marine Expeditionary Unit (MEU) to a Marine Expeditionary Force forward (MEF FWD). For the remainder of this document it may be assumed that a MAGTF is defined as a Marine Expeditionary Brigade (MEB) unless otherwise stated. The assumed composition of a MEB will be defined in a later section.

Future Marine Corps concepts of operation stress two capabilities: Operational Maneuver from the Sea (OMFTS) and Ship to Objective Maneuver (STOM). OMTFS emphasizes the sea as maneuver space to minimize the required closure range between

friendly and enemy forces, while STOM refers to the ability to transport equipment and troops to the objectives directly from ships without the operational pause associated with the build up of the "Iron Mountain".

In Sea Power 21 the Chief of Naval Operations has established sea basing as a future naval forces capability. The concept of sea basing implies a number of capabilities that are not inherent in our current expeditionary forces, among these are STOM, indefinite sustainment, selective offload, reconstitution of forces ashore, long range Naval Surface Fire Support (NSFS), and an increased capability in command and control. The Marine Corps has also established the requirement of a 3.0 MEB lift capability that is not currently met by our existing force structure.

The objective of this project is to take the required capabilities of a sea base and integrate them into a systems of ships that could be brought together to form a sea base. A secondary objective was to investigate the possibility of combining the capabilities of the Maritime Pre-positioning Force ship (MPF), an LHA replacement, and a Large Medium-speed Roll-on Roll-off (LMSR) onto a common hull form to be employed in a sea base or as the large deck amphibious ship of a Naval Expeditionary Strike Group (NESG). The advantage of using a common hull form is that it allows the shipyards to maximize the learning curve in production thereby reducing acquisition costs. Because the same hull form will be used in three applications the number of units produced will greatly increase when compared to a standard production run for a hull form, thereby providing long term stability to the industrial base.

II. DEVELOPING THE REQUIREMENTS

A. INTRODUCTION

By analyzing the requirements, the team understood, defined, and bounded the problem. In this particular case, the TSSE team needed to understand the mission of the system; by understanding the mission, the team became aware of the capabilities required to accomplish the mission. Requirements analysis helped the team to understand the interfaces between systems and how they affected each other. A master list of more detailed design requirements was produced at the conclusion of the requirements analysis phase; the team was well prepared to move on and explore possible system alternatives that could effectively perform the required capabilities.

The TSSE requirements analysis approach developed the design requirements through both Top Down and Bottom Up analyses. Figure 1 illustrates the TSSE requirements generation process.

The Top Down analysis concentrated on understanding the SEA Initial Requirements Document (IRD), clarifying issues with the SEA team by an iterative process, and generating a requirements list. The second portion of the Top Down analysis studied the Concepts of Operation (CONOPS) for sea basing and what capabilities were required to do sea basing. The analysis also required us to define a Marine Expeditionary Brigade (MEB) and its composition.

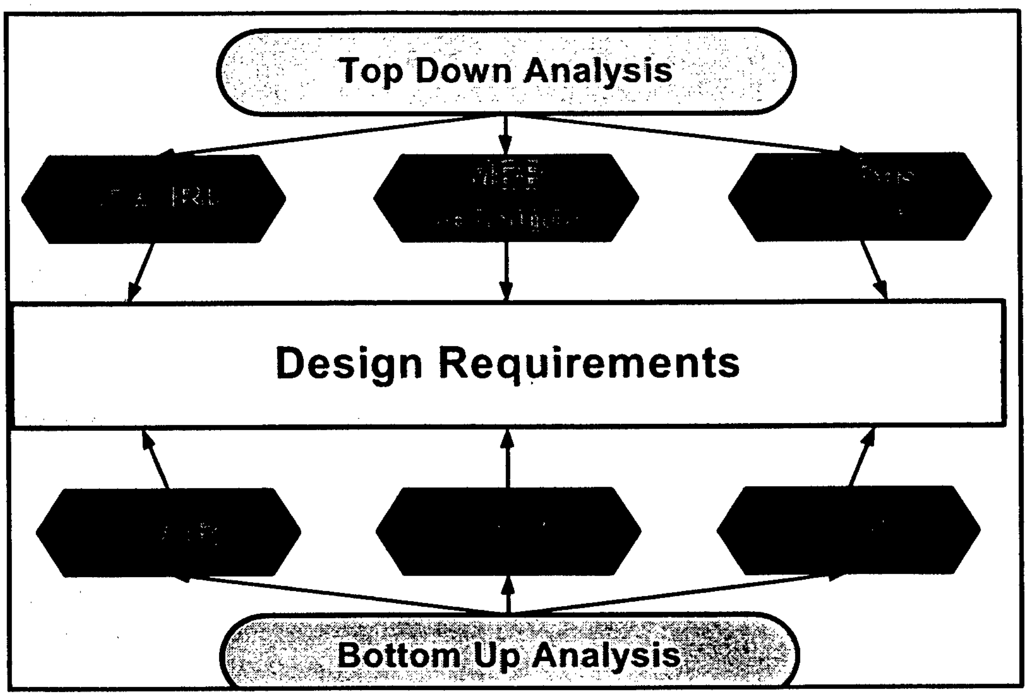


Figure 1. TSSE Requirements Generation Process

The Bottom Up portion of the requirements analysis focused on the LHA(R), MPF (F), and LMSR CONOPS, and current platforms in the naval expeditionary architecture. A list of required operational capabilities was generated and compared with the results of the Top Down analysis. A final, master Required Operational Capabilities (ROC) document was then created and used as the baseline design requirements. Interaction and iteration with the SEA team ensured that these design-level requirements were compatible with and met the intent of the system-level requirements (SEA IRD).

B. SEA INITIAL REQUIREMENTS DOCUMENT (IRD) ANALISYS

The Systems Engineering and Analysis (SEA) Initial Requirements Document (IRD) was the governing document in the

analysis and development of the requirements for the TSSE concept design. The IRD identified sea base capability gaps through the Systems Engineering Top Down and Bottom Up analysis. At this stage of the design process, it was crucial to the TSSE team to have a complete understanding of the IRD. Accordingly, the team commenced a detailed review of the requirements stated in the SEA IRD. Initially, two very important issues were quickly identified. The first issue was that the IRD did not define a Marine Expeditionary Brigade (MEB). The second issue dealt with documents concerning the sea base concept, each one of them having a different interpretation of the concept. The explorations of these two issues lead to the development of a base line for a notional MEB and a sea base Concept of Operations.

1. The Marine Expeditionary Brigade (MEB)

a. *Command Element (CE)*

The MEB command element provides command and control for the elements of the MEB. When missions are assigned, the notional MEB CE is tailored with the required support to accomplish the mission. Detachments are assigned as necessary to support subordinate elements. The MEB CE is fully capable of executing all of the staff functions of a MAGTF (administration and personnel, intelligence, operations and training, logistics, plans, communications and information systems, Comptroller, and COMSEC).

b. Ground Combat Element (GCE)

The ground combat element (GCE) is normally formed around a reinforced infantry regiment. The GCE can be composed of from two to five battalion-sized maneuver elements (infantry, tanks, LAR) with a regimental headquarters, plus artillery, an Assault Amphibian Battalion, reconnaissance, TOWs, and engineers.

c. Aviation Combat Element (ACE)

The aviation combat element (ACE) is a composite Marine Aircraft Group (MAG) task-organized for the assigned mission. It usually includes both helicopters and fixed wing aircraft, and elements from the Marine wing support group and the Marine air control group. The MAG has more varied aviation capabilities than those of the aviation element of a MEU. The most significant difference is the ability to command and control aviation with the Marine Air Command and Control System (MACCS). The MAG is the smallest aviation unit designed for independent operations with no outside assistance except access to a source of supply. The ACE headquarters will be an organization built upon an augmented MAG headquarters or provided from other MAW assets.

d. Combat Service Support Element (CSSE)

The brigade service support group (BSSG) is task-organized to provide CSS beyond the capability of the supported air and ground elements. It is structured from personnel and equipment

of the force service support group (FSSG). The BSSG provides the nucleus of the Landing Force Support Party (LFSP) and, with appropriate attachments from the GCE and ACE, has responsibility for the landing force support function when the landing force shore party group is activated.

e. Capabilities

The MEB is inherently expeditionary and utilizes a combined arms force. It includes a robust and scalable C2 capability. The MEB is designed to conduct a full range of operations from forcible entry to humanitarian assistance, and it is task organized for mission accomplishment. The MEB is capable of rapid deployment and employment via amphibious assault shipping, strategic air and sealift, or any combination of the three. It is capable of sustaining any operation for 30 days without the need for substantial re-supply. Its combat service support capabilities include supply, maintenance, transportation, general engineering, health services, and messing and lodging. The aviation capability includes tactical air support, anti-air warfare, air reconnaissance, EW, control of aircraft and missile engagement zones and overall C2 of the surrounding airspace over land and water.

2. Defining the MEB

The flexible nature of the Marine Corps made it difficult to establish a MEB baseline. In order to proceed with the design of the ship, the team had to establish the precise number of people, equipment, and supplies required to deploy a MEB. After careful consideration, the team established a notional baseline for a MEB based on the Marine Prepositioning Force

(MPF) MEB [1]. Figure 2 illustrates the organizational diagram for the MEB. Tables 1, 2, and 3 describe the major equipment, number of personnel, provisions, ordnance, and fuel required to sustain a MEB for 30 days.

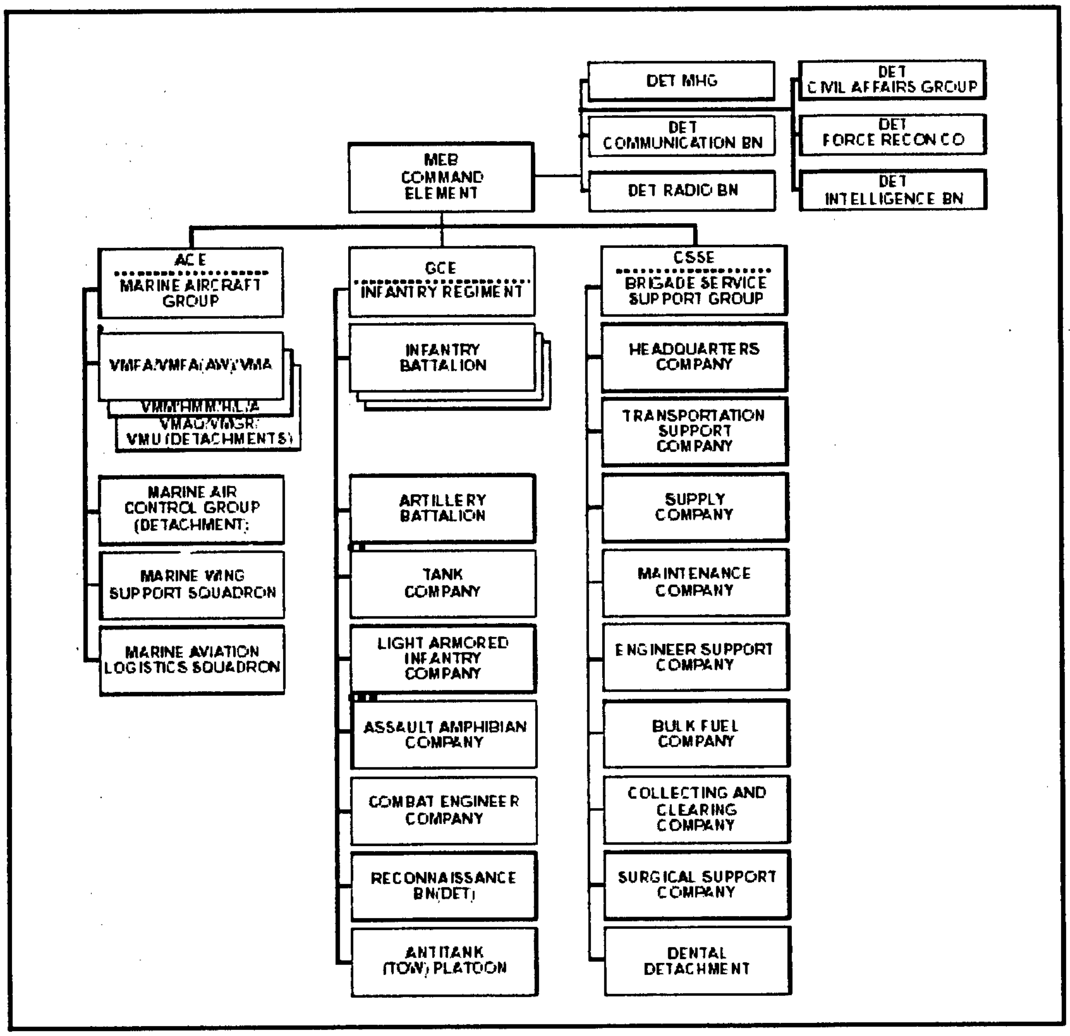


Figure 2. Marine Expeditionary Brigade [1]

Support Equipment		Major Weapons		Aviation Element		Total Personnel
Armed HMMWV	57	LAV AT	4	HLA	36	14,754
LVS Power Unit	109	LAV 25	14	AH-1Z	24	
LVS Wrecker	4	LAV LOG	3	UH-1Y	24	
LVS Trailer	53	LAV RECOV	3	MV-22	96	
5 Ton	282	AAVC7	9	JSF	36	
P-19 8	8	AAVR7	4			
HMMWV	473	AAVP7	96			
MRC-110	65	M1A1	58			
MRC-138	60	HMMWV (TOW)	72			
MRC-142	21	M198 Howitzers	30			
M970 Refueler	26					

Table 1. Equipment and Personnel for Conceptual MEB [2]

3. Sustainment

Perhaps even more difficult than defining what constitutes a MEB was to define its sustainment requirements. In this instance, the team decided to use CDR Kennedy's [3] thesis sustainment data to provide guidance on the amount of provisions, and ordnance, required by the sea base and the MEB ashore. Table 2, summarizes the amount of provisions and ordnance required by the sea base and MEB ashore. With respect to the amount of fuel required to sustain the MEB ashore, the team decided to utilize the data provided by the Center for Naval Analysis study titled "Fuel Requirements and Alternative Distribution Approaches in an Expeditionary Environment" [4]. Table 3, provides the amount of fuel in gallons required by the GCE, CSSE and the conceptual ACE. Table 4 presents the total weight and volume required including equipment, fuel, ordnance, and provisions for 30 days at a surge rate.

Commodity	Days	Std. Rate(tons/day)	Weight	Volume (ft^3)	Surge Rate(tons/day)	Weight	Volume (ft^3)
Provisions	30	95	2850	304000	95	2850	304000
Ordnance	30	550	16500	880000	687.5	20625	1100000
Total			19350	1184000		23475	1404000

Table 2. Daily Sustainment Rates, Weight, and Volume for a MEB [3]

			Surge	Sustainment			Surge	Sustainment
	# per ship	Burn rate (lb/hr)	# Sorties per day	# Sorties per day	Range (nm)	Speed (knots)	Fuel (gallon)	Fuel (gallon)
QTR	5	4,000	4.0	2.5	500	200	29,412	18,382
AH-1Z	4	800	3.0	3.0	650	152	6,037	6,037
UH-1Y	4	800	3.0	3.0	650	120	7,647	7,647
MV-22	14	350	4.0	2.5	500	240	6,005	3,753
JSF	6	2,000	3.0	3.0	500	875	6,618	6,618
							55,719	**42,437**
		gal/mile						
LCAC	3	16	9.0	2.0	50	35	14,400	3,200
LCU-R	2	0.86	4.0	1.0	50	15	344	86
							14,744	**3,286**

Table 3. Fuel Requirements for 30 Days of Sustainment (ACE, LCAC, LCU)

	Weight (ST)	Volume ft^3
Total Standard Rate	68,555	13,023,771
Total Surge Rate	139,880	26,573,774

Table 4. Total Volume and Weight

Establishing the MEB baseline was an important step in understanding the requirements stated in the SEA IRD. The baseline gave the team the necessary information and a working knowledge of how the MEB is organized and how it conducts operations. This knowledge, along with a firm understanding of

the sea base, provided a deeper appreciation of the system-level requirements defined in the SEA IRD.

4. The Sea Base

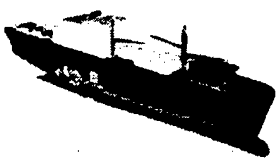
Understanding the sea base concept was a challenging task for the team. There was not an established architecture for the sea base, how it should operate, or how it should be employed. Also, as mentioned earlier, there were a multitude of documents that define the sea base. These concepts ranged from creating a sea base with current systems, to the Mobile Offshore Base (MOB) concept, which described the sea base as a series of massive, interconnected platforms that could land heavy transport aircraft.

The team approached the sea base study as one that explored the different capabilities that a sea base should possess. With that philosophy in mind, the team proceeded to review as many documents as possible which dealt with the sea base concept, merged these capabilities with the requirements presented in the SEA IRD, and generated a common list of required capabilities for the sea base.

C. BOTTOM-UP ANALYSIS

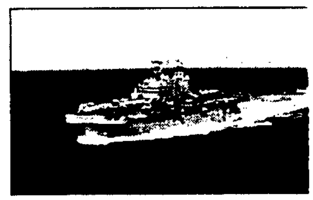
The Bottom Up analysis covered three proposed ship types: LHA(R), MPF(F), and a Large Medium-Speed Roll-on/Roll-off (LMSR) ship used to fulfill the role of an expeditionary support ship. The mission of the Bottom Up analysis was to ascertain the Navy and Marine Corps' platform-solutions approach to realizing the capabilities of the sea base. An additional purpose of this study was to determine if it made sense to combine the requirements of these three platforms into a single hull-form

design (with variants permitted). This study was conducted without reference to the SEA IRD. The TSSE sub-team assigned to conduct this study was tasked with writing a list of requirements for the single ship idea and making a recommendation on the feasibility of combining the three ships into a common hull form with multiple variants.



MPF(F)

LMSR



LHA(R)

Figure 3. Combining Three Concepts Into One Hull Form

A review of the most recent literature of these three ship concepts provided details on the types of capabilities these platforms could be expected to provide. Documents referenced were: (1) "The *Draft* Amphibious Assault Ship, General Purpose (Replacement) LHA(R) CONOPS (Revision 5)" [7]; (2) "The Maritime Prepositioning Force (Future) *Draft* CONOPS (1-03-02)" [8]; and (3) OPNAV Instruction 3501.199B (Required Operational Capabilities for the LMSR) [9]. Current LHD and LHA ship capabilities were also taken into consideration. The TSSE sub-team that conducted the Bottom Up analysis concluded that, based on the requirements, the idea of combining all of these capabilities into one hull form merited further consideration. Consideration of the number of ships in the sea base system and whether or not a single hull form or variety of hulls would be more appropriate to satisfy Sea Basing requirements is discussed in Part D of this chapter.

D. DESIGN OPTIONS

1. Number of Ships

Once a MEB baseline and an estimate of the weight and volume requirement were established, it was necessary to approximate the number of ships and their displacements. Tables 5 and 6 represent a 3-ship and 6-ship option respectively. Looking at table 5 for example, the total payload requirement is 140,000 short tons (ST). That figure divided by 3 ships resulted in a payload per ship of approximately 46,667 ST. The next five columns represent the payload to displacement ratio. In a warship such as a frigate or destroyer, the payload is approximately 25% of the ship's displacement. On the other side of the spectrum is a container ship where the payload is 80% of the ship's displacement. In table 6, the total payload was divided among 6 ships. Based on these two tables, the team decided that the 6-ship option was the best because the displacement per ship was more feasible. Furthermore, the team also estimated that the displacement would likely fall between 35% and 60% of the ship's payload. These conclusions were consistent with the current LHA/LHD class of amphibious assault ship characteristics.

3 SHIPS					Displacement & Volume per Ship		
			Warship Ratio	Somewhere in between			Container Ship Ratio
Payload	Total Payload	Payload per Ship	25%	35%	50%	60%	80%
Weight (ST)	140,000	46,667	186,667	133,333	93,333	77,778	58,333
Volume (ft^3)	26,600,000	8,866,667	35,466,667	25,333,333	17,733,333	14,777,778	11,083,333

Table 5. 3-Ship Family With Payload to Displacement Ratio

6 SHIPS					Displacement & Volume per Ship		
			Warship Ratio	Somewhere in between			Container Ship Ratio
Payload	Total Payload	Payload per Ship	25%	35%	50%	60%	80%
Weight (ST)	140,000	23,333	93,333	66,667	46,667	38,889	29,167
Volume (ft^3)	26,600,000	4,433,333	17,733,333	12,666,667	8,866,667	7,388,889	5,541,667

Table 6. 6-Ship Family With Payload to Displacement Ratio

2. Types of Ships

Other options explored by the team were the common platform design and the variants design. In the common platform design, all the ships would have exactly the same capabilities. In the variants design, a variety of hull versions would be built to host a smaller amount of related capabilities. For example, a ship of the sea base would be focused more on logistics capabilities, combat capabilities would be incorporated on another hull version. The following paragraphs describe both design philosophies' advantages and disadvantages.

a. *Common Platform Design*

<u>Advantages</u>: The common platform design would be better able to operate independently because each ship would possess the required self-protection capabilities called for in the Master List of Required Capabilities. A common platform design could be more flexibly redeployed without having to take a number of ships with it to provide the required capabilities.

Finally, the common platform family of ships would be inherently more survivable in that the required capabilities would be present on each platform and system redundancy would be optimized.

Disadvantages: The common platform design would have to be a larger ship and therefore might cost more money to procure.

b. Variants Design

Advantages: The variant design would be able to optimize on certain capabilities and these more focused areas of responsibility might lead to a more effective employment of the required capabilities.

Disadvantages: The variant design would be less flexible in terms of employing platform elements independently. Some variants would have little to no self-protection capability. There would be limited redundancy; if one ship was damaged, the entire system might lose a significant portion of the capabilities associated with that particular platform.

D. KEY TECHNOLOGY AREAS

The SEA IRD identified areas that implied technological innovations in order to make the sea base a reality. Most of these technological innovations could be traced directly to the capabilities required for *STOM* [6].

1. Replenishment, Distribution, and Interface

- Heavy-lift UNREP/VERTREP at sea (up to sea state 5)

- Drawbridge, skin-skin, (LO/LO, RO/RO)
- Lighterage technologies (e.g. HSV, LCU, small craft)

2. Cargo Handling Systems

- Automated warehousing technology to increase access and stowage density and provide selective offloading capability

3. C4ISR Technologies

- Integrated sea base network capable of monitoring and meeting demand

4. Operational Fires

- On demand and precise fire support provided by the sea base ships to reduce the MEB ashore logistics footprint

5. Unmanned and Automated Technologies

- To reduce the size and weight of platform(s) and achieve minimal manning requirements:
  - UAV/USV/UUV platforms
  - Automated warehousing/inventory
  - DC capabilities
  - Movement of ordnance associated with the landing force and assets of the ACE

E. CONCLUSION

Requirements analysis was comprised of a two-pronged approach. A Top Down analysis of the SEA IRD enabled the TSSE design team to deepen their understanding of the SEA requirements for the sea base. A review of important Navy and Marine Corps concept papers was conducted in order to verify

whether or not the SEA IRD articulated the system-level requirements that would meet the needs of the stakeholder. One salient issue that needed further clarification was the definition of a notional MEB. A Bottom Up analysis of existing and planned platforms associated with an expeditionary Sea Base was conducted in order to determine how the Navy and Marine Corps plan to achieve sea basing. A list of required operational capabilities was comprised as a frame of reference for the types of capabilities a single-hull design would need to incorporate in order to create a sea base. The Bottom Up study concluded that a single hull design was worthy of further study.

The results of the Top Down and Bottom Up analyses and the consideration of key technologies were merged into a single document that formed a baseline for discussion between the TSSE design team and the SEA team. The Master List of Required Operational Capabilities (Master ROC) is included in A. The Master ROC covers all required Sea Basing capabilities, key performance parameters of the system, and a number of questions to be answered by further study and interaction with the SEA team. Further iterations of the SEA IRD occurred based on the discussions held between the two teams. The final version of the SEA IRD is included in B. Finally, the Master ROC, as the more detailed list of requirements, served as the design requirements for the TSSE platform design.

III. ANALYSIS OF ALTERNATIVES

A. SINGLE SHIP DESIGN

The first design analysis was based on combining the capabilities of the MPF, LMSR and LHA ships into a single hull one-ship-does-all concept, which was referred to as the X-ship. Determining the size of the X-ship was the big challenge for this part of the project. Because three different platforms were being combined into one, some ship systems could be consolidated (from 3 propulsion systems down to 1) and others could not (vehicles storage volume could not be consolidated). A list of the capabilities of the three ship types (MPF, LMSR and LHA) was made to determine the requirements of the X-ship, using the LHA(R) CONOPS, LMSR ROC and the MPF(F) requirements as guidance.

It was then decided to estimate X-ship displacement using overall ship volume. There are graphs that relate the displacement of different amphibious ships with their respective total volumes. These graphs reveal a trend for the relationship between total volume and displacement. By estimating volume, we could then predict displacement, and displacement can be used to find all sorts of other ship characteristics

Next, the requirements of the X-ship were studied, to determine how much volume was needed for each requirement. This was the same method of ship size estimation that was being used by the second design analysis team. It was important to use the same estimation methods, so that the results were based on the same data.

In fact, one of the big challenges with the Analysis of Alternatives part of this project was to use the same data

between the teams. A description of the equipment in a future MEB was not easy to find, because it depends on concepts like STOM, which have not yet been fully defined. All three teams worked together to determine these numbers, and the resulting equipment requirements used by each team were the same.

Because a one-ship design is required to perform all missions of the three ship designs it is supposed to replace, it was expected to be large. There was such a wide variety of components that the ship was required to have, including a well deck, a hanger deck, hospital, Marine Corps berthing, storage for vehicles and supplies, weapon systems, a large number of antennas, machinery repair spaces, etc. The ship also had to be able to interface with supply ships to onload large amounts of supplies, much more than is currently done via unrep. This requirement is needed so the ship can remain on station and continue to sustain operations ashore for a long period of time, possibly indefinitely. It was clear that the combination of all these different capabilities was going to lead to a large ship.

Current Marine Corps amphibious forces can be broken up into MEUs and MEBs. An MEU is contained aboard one LHA, one LPD and one or two LSDs. One MEB is composed of three MEUs, additional aircraft and some large cargo ships that carry equipment, and troops for this equipment, troops which are flown into the area. Using one X-ship to carry an MEU was predicted to yield a ship that would be in excess of 110,000 LT, larger than any naval combatant ever constructed. A ship of that size raises all sorts of concerns, everything from an inability to transit through any existing waterway to affordability. It was decided to use two ships per MEU, and 6 ships per MEB. One thing that was noted during this process was the incorporation of the MPSRON into this one-ship-does-everything concept. Doing

this means the equipment normally staged on pre-positioned cargo ships was now going to be carried on the combatant. This was clearly going to lead to an increase in the size of this vessel over previous amphibious vessels such as the LHD. The anticipated increase in aircraft required to perform STOM was also seen to increase ship size.

Estimating internal volume requirements was difficult. Care was taken to realistically account for all vehicles that were to be carried, as well as aircraft, supplies and personnel. The hangar volume was based on a given area with 30 feet of overhead. The hangar area was based on the combined footprint of all embarked aircraft. Each single ship was given two well decks, each of which were sized to the well deck of the LHD. Berthing volume was estimated using common sense, and all volumes and calculations were listed on a MICROSOFT EXCEL spreadsheet. For brevity, this spreadsheet is not included in this report but it is available upon request. After volume calculations were completed, they were increased by 30%. This was done to account for space needed because it was felt that volume in the storage areas had been grossly underestimated. Accessibility is a big part of selective offloading, and more volume was thought to be needed to properly account for this capability. In addition, this extra volume served to account for any systems that had been overlooked, and to allow for a volume growth margin on the ship. This led our ship to have a volume of around 8.1 million cubic feet, which led to a

Category	Approximate Value
Total Volume	8,056,952
Displacement	70000
Length	950
Beam	140
Draft	40
Number of well-decks	2

displacement of around 70,000 LT.

During the comparison between the three different AOA options, the single ship design was far larger than the other ships, because the other designs did not incorporate a 30% margins. With this margin removed, the one-ship design dropped to around 48,000 LT, which better compared with the other two designs.

B. LMSR/MPF WITH LHA DESIGN (ALTERNATIVE B)

The second design analysis was based on an MPF/LMSR variant with a separate LHA design. The first step in the analysis was to divide the requirements between the ship types. The next step was to determine the weight and volume requirements for the equipment that each ship would carry. Once the volume and weight requirements were calculated, a graph was used to extrapolate the final length, beam, volume and displacement of the two ships.

In order to divide the requirements between the ships, it was decided that the MPF/LMSR would function solely as the supply support vessel while the LHA would assume all of the combat roles. As a final constraint, an attempt was made to divide the requirements such that the weights and volumes would come out roughly equal for both ships. The goal was to create variants of a shared hull form. To further define the size of the two variants as well as make deployment of these ships easily scalable, it was decided that each pair of ships would carry the equivalent of a Marine Expeditionary Unit (MEU). The LHA with an MPF/LMSR variant could then be easily scaled. If a MEB were needed, for instance, the theater commander would simply deploy three LHA's with three MPF/LMSR ships knowing that

they would have all of the equipment available for a MEB sized force.

Having laid the ground rules for the division of requirements, the LHA(R) CONOPS, LMSR ROC and the MPF(F) requirements were divided among the two platforms. Every requirement that was deemed to be of a combat nature was delegated to the LHA variant. If the requirement seemed to entail more of a supply/support role, it was assigned to the MPF/LMSR variant. When this was completed, the various amounts of equipment weights and volumes were put on the variants according to their use. In example, the MPF/LMSR variant was given a certain number of MV-22's to carry stores to the beach for use in STOM. Once all the volumes and weights were computed, a final weight and volume was assigned for each variant. See Appendix C for a list of the equipment carried by each variant.

The first iteration for the variants turned out to be very successful in terms of the ship displacement. The displacements for the ships were nearly equal, which was a primary goal for the study. To actually determine what the final displacements for the ships were, a parametric study was conducted. By determining the relationship between the overall volume of the ship and its full load displacement a linear relationship was determined and utilized to estimate the full load displacement of the ships. A detailed volume calculation for each ship is shown in Appendix C. See Table 7 below for the basic characteristics for each ship.

	LHA Variant	MPF/LMSR Variant
General Concept	Combat Variant	Logistics/Supply Variant
Number per MEB	3	3
Ship Crew	~1200 Sailors	~400 Sailors
Marines Crew	~2000 Combat Marines	~3000 Marine Support Personnel
Volume	7.5 Million ft^3	7.2 Million ft^3
Displacement	~60,000 LT	~52,000 LT
Dimensions	L: ~873 ft, B: ~140 ft, D: ~30 ft	L: ~873 ft, B: ~140 ft, D: ~30 ft
Speed	25 knots	25 knots
Aircraft	JSF: 6, CH-53: 8, MV-22: 3, AH-1Z: 3, UH-1Y: 3	CH-53: 3, MV-22: 4, AH-1Z: 1, UH-1Y: 1
Combat Systems Capabilities	Basic Air, Surface, Mine and Undersea Warfare Capabilities	

Table 7. MPF/LMSR and LHA Variant Characteristics

C. LHA/MPF WITH LMSR DESIGN (ALTERNATIVE C)

The LHA/MPF with LMSR alternative combines two ships on similar hull forms but different structural requirements, layouts, and missions. The division of resources is as follows: the LHA/MPF will have the bulk of troops, the combat systems, C4ISR, and ACE support. This will be more like a combat or command ship. The LMSR will carry fuel, provisions and ammunition, support a hospital and interface with commercial shipping. This will be more like a support or MSC type ship. The combination of these two platforms are expected to carry a MEU+, or a force equivalent to the size of a present day Amphibious Ready Group (ARG), plus the difference between the MEU and a third of a full MEB.

The main engineering considerations taken into account during this analysis were indefinite sustainment, selective offload capability, survivability and scalability. The indefinite sustainment requirement drove the fuel and combat loading, maintenance and logistics requirements that made the

analysis volume driven vice a weight driven design. The selective offload capability, more important for the supply variant, drove the internal layout for the ship such that there exits a simple means of accessing any vehicle or piece of cargo at any one time during an offload process and was accounted for using a volume margin. Survivability was selected due to the need for one or more of these ships to be able to support any portion of the MEB at any one time. While a specific number of these ships may be able to carry a full MEB, it was desired to have a MEU or similar size MAGTF completely supported by a lesser number of ships as the MEU size force is historically the most prevalent size MAGTF used. Finally, survivability was considered from the standpoint of combat systems defensive ability as well as ability to fight the damage control battle.

The approach used to determine these rough estimates compared a top down approach and bottom up approach. The top down approach involved a graphical comparison estimate based on cubic number and volumetric capacity of current amphibious ships as well as the MPF 2010 TSSE design of 1998.

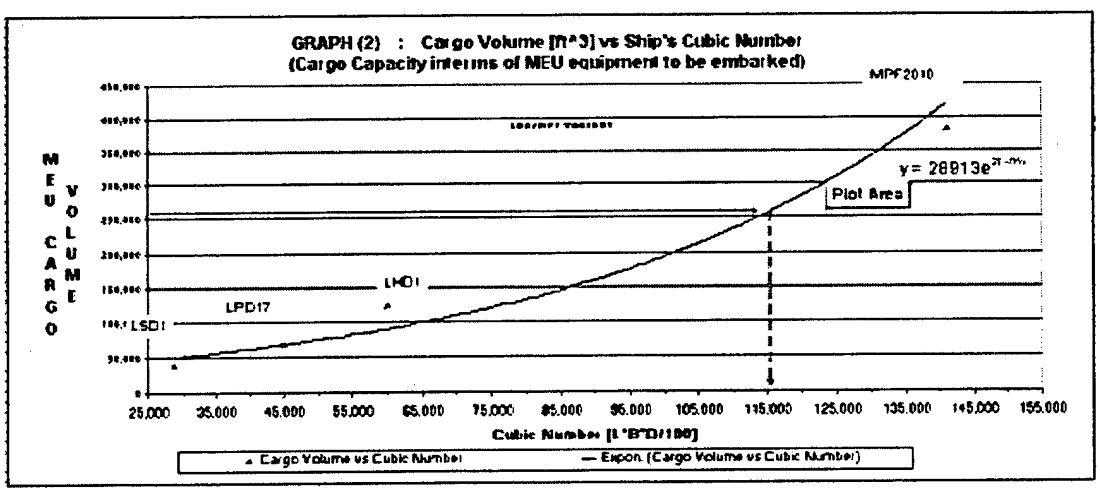


Figure 4. Amphibious Ship Cargo Capacity Comparison

The curve in Figure 4 shows this comparison. Adding the known volumes for landing craft, replenishment requirements, major communications equipment, and engineering equipment made an estimated volume of the MEB equipment. This total volume was then doubled in order to account for space between equipment and required accessibility. A cubic number of approximately 116,000 was derived from the graph. This value equates to an estimated ship volume of 11,500,000 cubic feet. Based on the fact that the cargo estimate was calculated from block estimates of the equipment rather than their actual volume required, the top down estimate was determined to be an overestimate. Given the data that was available for the MEB, however, this estimate could not have been improved.

The bottom up approach was driven by the volume and weight requirements of an MEB and Sea Base system. Rough weight estimates were made of all of the following: known MEB equipment to include aircraft, a medical facility, habitability spaces, combat systems, basic ammunition, propulsion and electrical requirements, necessary spaces for a crew size similar to that of an LHD plus one sixth of the MEB, an AIMD facility and fuel estimates. These requirements were then divided on a percentage basis between the two ships based on their given missions as described above. Table 8 below shows the percentage breakdown for each ship.

Table 9 shows the comparison of the LHA/MPF with LMSR alternative ships. It is evident that the top down and bottom up approaches did not agree, however, this allowed the team to understand the magnitude of ship or family of ships that had to be build in order to meet the requirements of the project.

Percentage Breakdown of Spaces:		LMSR	MPF/LHA
Propulsion/Aux/Elect		5.05	5.01
Fuel			
Ariwing		0.63	2.51
Ship		8.04	7.97
MEB		20.00	18.61
Habitability		46.77	32.34
Combat Systems		0.42	0.65
C4I		0.42	0.67
Hospital/Medical Facilities		1.99	0.49
Misc Compartments		1.33	1.51
Hangar Deck		3.48	18.48
Well Deck		11.86	11.77
		100.00	100.00

Table 8. Space Breakdown by Percentage for LHA/MPF plus LMSR Alternative

	TSSE Design 2002	
	LMSR[K]	LHA/MPF[LM]
	SAME HULL FORM	
Length (ft)	825	825
Beam (ft)	130	130
Design Draft (ft)	TBD	TBD
Depth(ft)	107.23	107.23
Length/Beam ratio	6.35	6.35
Length/Draft ratio	TBD	TBD
FL Disp (LT)	0	51,098
Volumetric Displacement	0	1,788,427
Displ-Length ratio	91	91
Ship's Cubic Number	115000	115000
Speed - sustained	27	27
Speed -Length ratio	0.94	0.94
Installed SHP	128,200	128,200
Features		
Flight Deck Spots (include 6 x Landing spots CH-53)	28.17	64.98
Well Deck (#LCAC)	2	1
Vehicle Deck Area [ft^2]	135,000	50,000
Volume MEU EquipmCarried(not incl troops)	1,358,196	2,521,848
Cubic Volume of Ship Hull[ft^3]	11,500,000	11,500,000
Detail Volume req [ft^3]	9,423,513	10,699,049
Discrepancies	2,076,487	800,951

Table 9. Results of LHA/MPF with LMSR Alternative

Overall, this alternative does not effectively combine the most important resources of the three platforms evaluated into two, leaving an unbalanced division of functionality between the

two ship types and unanswered questions with regard to operational concept.

D. EVALUATION CRITERIA AND CONCLUSIONS

To evaluate the three previously discussed options the team developed a set of design criteria based on the priorities and assumptions given in the SEA-IRD, the operational experience of the officers on the team, and the input from the faculty advisors. In addition to our own experience, several members of the team traveled to San Diego to discuss operations with units that had recently deployed on a large deck amphibious ship and to take a guide tour of that ship.

The total score was divided into two areas. The technical score comprised 75 % of the total score and operational score was weighted 25 % of the total score. The technical criteria were broken down into nine distinct functional areas that the ship would have to perform and then weighted to reflect the importance to the overall mission of each area as seen in table 10. Amphibious warfare (AMW) was given 40 % of the total weighting because the reason for operating from a sea base is to project forces ashore without requiring a land based staging area. Implicate in the area of amphibious warfare is the ability to conduct air operations for combat aircraft, and a key enabler to achieving the operational concept of STOM is a robust aviation capability. Logistics (LOG) was given the next highest weighting at 28 % due to the demands placed on the design by the requirement to be indefinitely sustainable. Fleet Support Operations (FSO) and C4ISR were weighted at 11 % and 10 % respectively and round out the major contributors to the evaluation criteria. Fleet Support was rank slightly higher than C4ISR due to the requirement to support a multitude of Navy

and Marine Corps systems from the sea base. It was determined that C4ISR was important enough to have it own evaluation area, but that there would be some overlap with amphibious warfare in this area that would combine to give C4ISR an effective overall rating higher than 10 %.

The remaining areas of evaluation are mine warfare (MIW), mobility (MOB), anti-surface warfare (ASuW), anti-air warfare (AAW), and under sea warfare (USW). These areas comprise 11 % of the total weighting because it is assume that the escorts and the CSG will provide the majority of the sea base's capabilities in these areas. However, it would not be prudent to design a ship that will become the center of gravity for the sea base and not give it at least some self-defense capability. With that thought in mind, the areas mentioned above were included in the evaluation criteria but given an appropriate weighting in comparison to the primary mission areas.

Warfare Area	Weighting Factor (in percent)
AMW	40
LOG	28
FSO	11
C4ISR	10
MIW	5
MOB	2
AsuW	2
AAW	1
USW	1

Table 10. Evaluation Criteria

Each of the options was then brief to the entire team and faculty and assigned a numerical score between one and five

(five being the highest) by each of the team members in the technical and operational areas. (Note the team leader and faculty did not vote to avoid showing preference for any single design.) The results of the team's evaluations were then put into a spreadsheet and a total score for each option was calculated in accordance with the evaluation criteria. The spreadsheet results were then brief to the team and discussed to ensure that majority consensus was reached with regard to the design option to send to the phase III (Conceptual Design).

Figure 5 shows the final results for the four heaviest weighted technical areas, which encompasses 89 % of the technical score, as well as, the scores for operational concept and total score. From figure 5 it is clear the team felt that option C (single ship design) provided clear advantages in the areas of amphibious warfare, C4ISR, and operation concept. It is also clear that in the opinion of the team none of the option possessed an advantage in the area of logistic. The total score favors option C and is the option that is selected to move to Phase III, but with some concerns in the area of the re-supply ship for this concept.

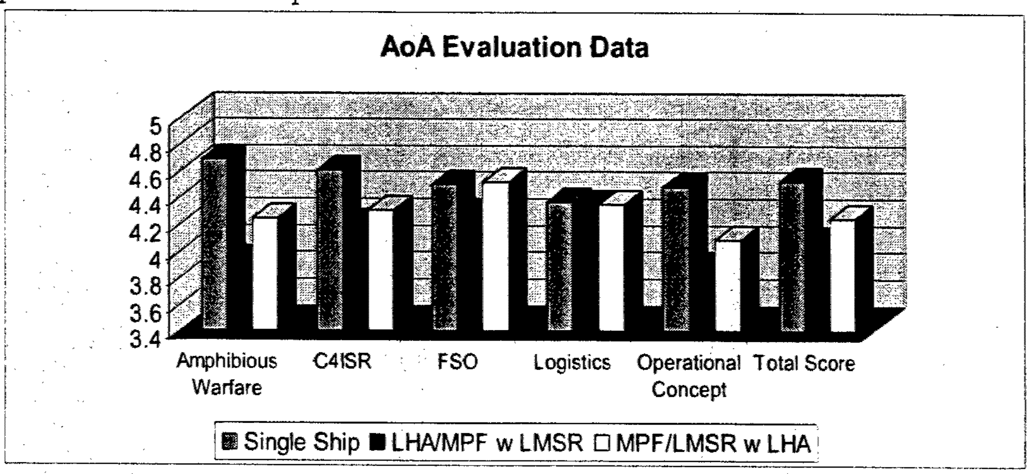


Figure 5. Analysis of Alternatives results.

As mentioned in the section concerning this alternative, six of these ships will carry a MEB and then three will be used as supply ships. The team was concerned that the supply ship would be over design and too expensive to make the concept practical. To resolve this issue it was decided that the ships would be design to a high level of modularity to allow all the warfare essential components to be added after initial construction or removed in during shipyard availability. As a result, the ship would be constructed as a supply ship with all the appropriate auxiliaries to support the later installation of the combat suite, and if necessary could be brought back to the shipyard to be converted to a combatant should the need arise.

IV. DESIGN PROCESS

A. DESIGN PHILOSOPHY

In addition to the design requirement given in the IRD, the team developed a design philosophy to aid in making sound engineering decisions. As indicated in the evaluation criteria weighting factors used in the analysis of alternatives, amphibious operations and logistics were key components of this design and encompass the concept of sea basing. The following list of priorities in order of highest to lowest were used in the decision making process when conducting design tradeoffs.

Priority	Weighting Factor
1. Aviation Capability	High
2. Indefinite Sustainment	High
3. Operational Flexibility	High
4. Combat Systems Defensive	High
5. Modularity	Medium
6. Manning Reduction	Medium
7. Speed	Medium
8. Maintainability	Medium
9. Cost	Low
10. Combat Systems, Offensive	Low
11. Appearance	Low

Table 11. Design Priorities

Aviation Capability

Aviation capability is the single biggest improvement this platform must make over existing large deck amphibious ships. The IRD sets a requirement to operate from 25 to 250 NM from the beach and be able to conduct STOM as deep as 200 NM inland with the ability to reconstitute forces ashore in response to changes in the operational objectives. Once the forces are deployed then they must be sustained for an indefinite period of time. The only way to effectively deliver troops and maintain a supply chain over 400 NM miles that covers both land and water is through the use of aviation assets. To ensure that the maximum sortie generation rates could be met the aviation capabilities were given the top priority.

Indefinite Sustainment

The requirement to operate for an indefinite period of time from a sea base was the second key aspect of this design. To be effective in mission accomplishment and a formidable threat to the enemy forces the sea base must be able to stay on station for a significant period of time. Since it is impossible to predict the duration of any conflict with reasonable accuracy, the length for sustainment was determined to be indefinite. It is not intended that the sea base would be on station until the date of its decommissioning, but should be able to conduct operations at full capability until relieved by another unit. This issue is at the heart of sea basing. Without the ability to move all items necessary for combat and support through the sea base it becomes just another large combat ship.

Operational Flexibility

Again, the uncertainty of future conflicts mandates that the forces dispatched to fight in them be able to quickly and efficiently reconfigure to meet the changing threat. This can happen on many levels. In the field, the ability to insert, retract, and re-insert at a different point is a highly desirable ability now referred to as reconstitution of forces ashore. On a larger scale the ability to divide the sea base into smaller self-sufficient units capable of covering a number of lesser objective that are geographically separated, and still retain the overall operational characteristics of STOM and indefinite sustainment, would allow the theater commander greater flexibility in addressing multiple objective scenarios. At the Theater CINC level the ability to rapidly deploy a MEB for 30 days using only three NESG provides coverage for the majority of the conflicts that may fall under his authority.

Combat Systems, Defensive

The assumption of the NESG escorts and the presence of a CSG in the theater of operation significantly reduced the combat system requirements for this design. As a result the combat systems were given a lower priority than it would have received if the design was for a cruiser or destroyer. The requirement to operate in the littorals however does demand that the ship have a significant self-defense capability, especially with regard to shore based surface to surface missiles, small boat attacks, and mines.

Modularity

Modularity is seen as one of the key enablers in controlling the cost of this design and ensuring future

upgradeability. Both combatant and supply will be constructed on a common hull form, and to the maximum extent possible will share many of the same internal and external arrangements. Where it is not possible to configure both ships the same every effort will be made to use modularity to allow the conversion from one type of space to another. In the space where modular units cannot be used removable bulkheads and other semi-permanent structures will be erected. These efforts should allow a supply variant to be converted to a combatant during an extend availability.

Manning Reduction

The manning levels for this ship design will be set at the minimum number needed to accomplish the mission and still provide a margin for safety and quality of life. In appropriate areas of the design, technology solutions should be researched to reduce the crew size as well as increase the efficiency and reliability the ship's operations.

Speed

The speed and endurance requirements for the design do not present a significant enough design challenge to allow them to become major design driver. When compared with the size and speed of an aircraft carrier the estimated size of this design should not limit speed to less than 25 knots. In limited operational scenarios it may become desirable to maintain speeds in excess of 30 knots for short durations, and thus should be given some consideration in the design.

Maintainability

Due to the anticipated high initial acquisition cost of these platforms and the limited number of facilities that could maintain a ship of this size it is necessary to extend the life of these ships as much as possible. This is one method of offsetting the high front-end cost for these ships. Additionally, a lower cost of ownership over the life of the ship will free up more money for construction and upgrades.

Cost

Due to our limited ability to model and predict certain aspects of this design the cost estimate may be the most inaccurate portion of this design. For this reason cost should not be a high priority design driver. It is also felt that the cost for a platform that could truly deliver the sea basing capability could easily be justified. More emphasis should be placed on reducing the cost of ownership and future upgrades than the initial acquisition costs.

Combat Systems, Offensive

The offensive capabilities for the sea base have been delegated to the escort units and the CSG. The requirement for NSFS in the IRD applies to the sea base as a whole and not each individual ship. However, since this ship will be operating mainly as an amphibious assault ship it should have some capability to support the GCE ashore. Because this capability is present in other platforms of the sea base it should be given a lower priority than the combat systems defensive capabilities discussed earlier.

Appearance

The appearance of this ship should be one of dominating and impressive stature, as it will undoubtedly become a capital warship and a symbol of American strength and presence around the world. This should not take precedence over other design consideration that would in anyway reduce the combat readiness of this platform.

B. DESIGN OBJECTIVES

The design objectives for this project were derived from the guidelines established by the SEA team and the faculty advisors for the TSSE program. The SEA Team developed a set of system-level requirements designed to describe the kind of solution needed to cover the gap in sea basing capabilities. The presentation of the system-level requirements by the SEA team to the TSSE design team initiated a requirements analysis phase that was meant to be iterative and interactive between the SEA team and the TSSE design team. This process is more thoroughly explained in Chapter II of this report. Clearly, therefore, a very crucial design objective was to adhere to the Systems Engineering methodology as defined by the SEA team and adapt the methodology to this project.

The design objectives also involved the directives and guidelines of the faculty advisors. The faculty directed the TSSE design team to explore the interaction and interfacing of various subsystems such as hull, propulsion, and combat systems in order to produce a balanced ship design that satisfied the system-level requirements established by the SEA team. The goal was to integrate the representative academic disciplines of team members to create a kind of synergism in achieving the end

product. This would, if done properly, not only achieve a better design but also enhance the learning process of all involved. Employing Systems Engineering principles throughout the project was also a key aim of the faculty and, therefore, an important design objective.

C. DESIGN CONSTRAINTS

One of the primary considerations in developing our design constraints, and a design requirement from the SEA-IRD, is the ability to gain access to major ports in the United States. Along with the above requirement, another goal of this project is to explore the impact of future technology on ship designs. In order to ensure a realistic and relevant product the design was bounded by the following parameters:

1. Draft no greater than that of a nuclear powered aircraft carrier.
2. Height above the waterline no greater than that of a nuclear powered aircraft carrier.
3. Overall length no greater than 1000 feet.
4. Displacement no greater than 100,000 LT.
5. Beam no greater than 300 feet
6. Technology that could be ready for shipboard implementation by 2020.

The reference to the draft and height of an aircraft carrier ensured the ship could gain access to any port currently capable of receiving an aircraft carrier. Constraints three through five were set to control the size and cost of the design and to ensure that a reasonable power plant could be implemented to meet the SEA-IRD speed requirement. Constraint number six was set to limit the technology research to a time period that the

advances in technology could be predicted to some degree of certainty. By adhering to the above constraints the product of this project should be a design that is achievable in the near future and provides the Navy and Marine Corps a significant improvement over current expeditionary platforms.

D. TECHNOLOGY ENABLERS

1. Flight Deck

Manning reduction and increased throughput of supplies to the forces ashore were extremely important considerations in our ship design. The flight deck presented an excellent opportunity to apply technologies such as robotics to achieve the desired manning and throughput results. The following paragraphs describe some of the possible uses of automation and robotic technologies that were incorporated to the flight deck.

SENSOR TECHNOLOGY

1. General Description

Because the flight deck was design without a traditional tower, the flight deck will have Radio Frequency Identification (RFID) sensor grid that will keep track of aircraft, equipment, and personnel movement on the flight deck. The sensor grid will relate each entity location into a flight deck model situated in flight deck control. The sensor grid will also serve as a navigation grid for unmanned flight deck equipment. The RFID transponders and readers form the basis of the flight deck sensor grid. The passive transponders offer a general-purpose read/write capability that can be programmed with description data such as type of aircraft, mission, maintenance status etc.

User data is written to and read from memory blocks using a non-volatile EEPROM silicon technology. Each block is separately programmable by the user and can be locked to protect data from modification.

Multiple HF transponders that appear in the Readers RF field can be written to and read from by using the Simultaneous Identification (SID) number, which is programmed and locked. The Reader Module handles all RF and digital functions required to read multiple transponders.

2. Transponders

The HF transponder consists of a resonance circuit assembled on a foil with a flip-chip mounted microchip. An aluminum antenna is used as inductor and 2 layers of aluminum on the top and bottom side of the foil function as capacitor. The two layers are contacted through contacts. To protect the transponder from corrosive influences, the aluminum is covered with gravure-resist ink. The HF transponder is a low power, full duplex transponder for use with passive contact less identification transponder systems. The transponder is designed to operate with a HF carrier frequency. Downlink communication (Reader to Transponder) is accomplished by pulse width modulation; Up-Link communication (Transponder to Reader) is implemented with sub-carrier modulation. Both, Up and Down Link are frame synchronized and Cyclic Redundancy Check (CRC) check sum secured. The device provides 256 Bit non-volatile user memory with block wise read/write and locking functionality. Each transponder has a unique address that is factory-programmed and 32 bits long (232 different addresses). Each transponder can be addressed with this unique ID or one can use the non-addressed mode. A mechanism to resolve collisions of a

multiplicity of transponders (Simultaneous Identification - SID) is also implemented. This special feature allows multiple transponders to be read simultaneously. The SID mechanism offers the capability to inventory in a very short time a large number of transponders by their unique address provided they are within the reader operating range.

3. Reader

The RS232 Interface module converts the asynchronous Transistor-Transistor Logic (TTL) signals of the Reader Module to standard RS232 signals. The TTL input/output interface is augmented with a serial interface when the reader module is combined with the RS232 Interface Board. This board provides an asynchronous serial communication interface that can be directly connected to commonly used system controllers or PCs [10,11].

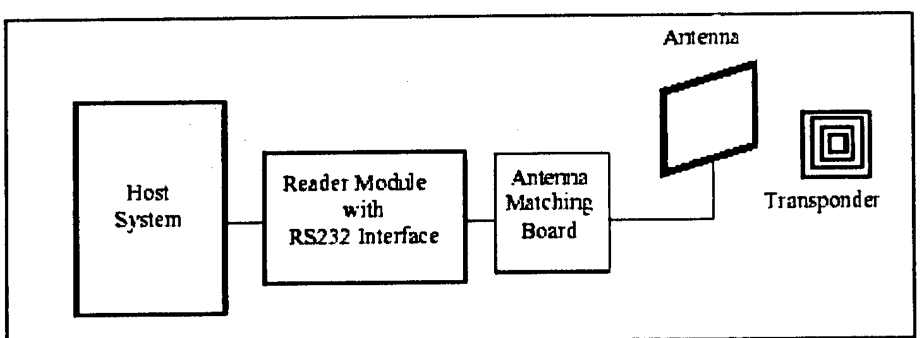


Figure 6. Transponder Reader System

ROBOTICS

Today, most of the operational robots carry out tasks which are too dangerous for humans to perform. Today, the enormous advances in machine vision and autonomous navigation will

combined with software technology like Artificial Intelligence (AI) and Expert Systems (ES), and will bring a revolution in robotics. In a not so distant future, robots will perform a larger, more complex variety of tasks.

1. Fueling Systems

Currently, fueling systems on a large flat top consists of pump rooms located around the deck edge. Fueling teams composed of two to three personnel unroll a fueling hose from a rail, start the pump and fuel the aircraft. In the propose fueling operational concept, a robotic vehicle similar to the one depicted in Figure 7 will navigate through the flight deck to a designated aircraft pit spot. The sensor grid previously described will served as a reference map to the robot while its advance obstacle and collision avoiding algorithm software will guide it through a labyrinth of aircraft and equipment. The Multi-resolution Automated Path Planning Evolutionary Routing (*MAPPER*) genetic algorithm (GA) is incorporated into the Unified Control Solution for path planning of autonomous vehicles aboard Navy ships. *MAPPER* functions as a basis for planning when explicit configuration space computation is not feasible. *MAPPER* has already been evaluated on problems of 2 to 6 degrees of freedom, including multi-degree-of-freedom (dof) ground vehicles working in maze-like corridors and cluttered areas [12].

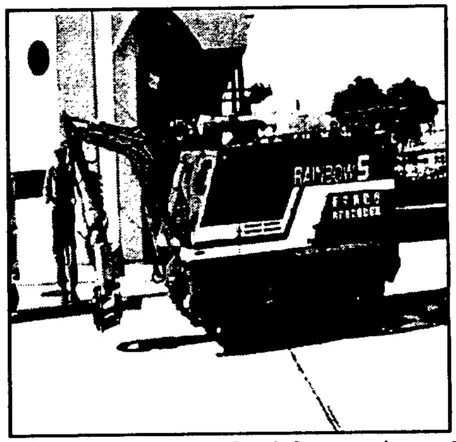


Figure 7. Multifunction Robotic Vehicle

The robotic vehicle will approach the pit stop where the aircraft is waiting to be served, unlatch the top of the hydrant fueling system [13] illustrated on figure 8 and attached its probe to the fueling valve. Meanwhile, the robot identifies the aircraft fueling points, and deploys its fueling arm to fuel the aircraft. The described sequence of events is not so far from reality. Scientists and engineers are currently working in these types of problems. Research has already tested avoidance collision algorithms in ground vehicles (1997) and air vehicles (2001). The next step is to fully test the Unified Control Solution vehicles under shipboard and sea state condition [12].

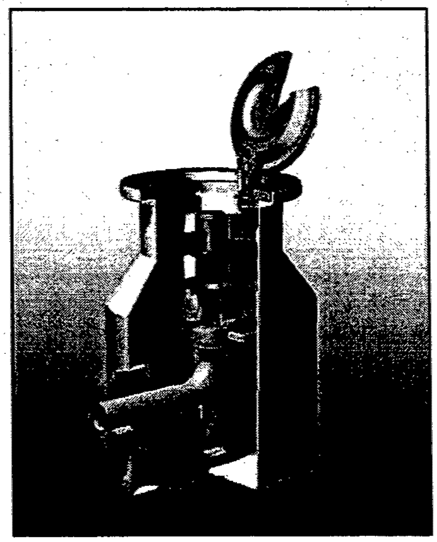


Figure 8. Hydrant Fueling System
(Source: Dabico Inc.)

2. Fire Fighting Systems

This prototype of robotic firefighter has been developed to withstand temperatures of up to 800 degrees centigrade. All the wiring has been upgraded to survive in the heat of a fuel fire. The robotic firefighter is controlled remotely. The driver can see what is happening in the blaze through two cameras, infrared and standard, which beam back video pictures. At the front is a powerful grabbing arm, which has multiple functions such as debris and ordnance removal. Even though this vehicle is still man operated, it could potentially replace an entire hose team of about five to six people. In the future, the incorporation of AI and ES will eventually make this type of robot fully capable without human intervention.

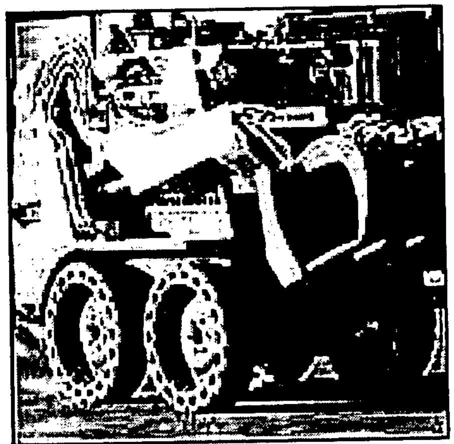


Figure 9. Robotic Firefighter

3. Towing and Tie Down Systems

Depicted in figure 10 is an omni directional vehicle [14] that will tow aircraft and other pieces of flight deck equipment [15]. Equipped with the advance navigation and anti-collision software algorithm, this vehicle will navigate to the designated place on the flight deck where the aircraft is to be towed. Once in position, the vehicle will deploy its robotic arm and attach it to the aircraft's main landing gear. Meanwhile, two smaller robots will deploy from the same vehicle and position themselves near to the secondary landing gear. Using the sensor grid as a reference map, the towing vehicle will tow the aircraft to its designated spot. Once in position, the towing vehicle will command the chock and chain robots to deploy and complete the aircraft tie down.

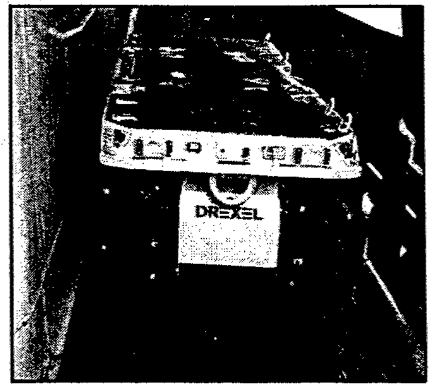


Figure 10. Omni Directional Vehicle

The omni directional vehicle will have several variants that will considerably enhanced flight deck operations. A different vehicle variant will have a set of forklifts and a conveyor like cargo surface. The vehicles will a have a cargo capacity of 12,000. The forklift will pick up cargo pallets and lift them up. When the forklift reaches the cargo surface, the conveyor will place the load on the cargo surface. Subsequent loads will be loaded to the vehicle until either the load reaches the maximum cargo weight capacity of the vehicle or the cargo surface is full. The loaded vehicle will transport the load to the designated aircraft or spot, and unload the load in a similar manner as described above.

Another variant of this vehicle will be an integrated maintenance and support vehicle. Maintenance personnel will have diagnostic software and the necessary tools to perform basic diagnostics and maintenance. The vehicle will automatically keep track and inventory its tools, preventing possible Foreign Object Damage (FOD) to aircraft engines.

2. At-Sea-Transfer and Logistics Automation

An important element of the design philosophy for the Sea Force ship was manning reduction. Historically, in large ships such as LHDs and CVs, the supply department is one of the most

manpower demanding departments. Ironically, it is by far, the department that could be benefited the most by automation systems. For this reason, the Sea Force Ship design has incorporated a number of cutting edge technologies in order to maximize throughput and minimize manning.

The Office of Naval Research (ONR) has undertaken an ambitious program that concentrates in future Expeditionary Logistic capabilities. One of the studies focuses in particular on Shipboard Internal Cargo Movement [16]. The following paragraphs describe some of the technologies being research by ONR, how these technologies are incorporated in the Sea Force Ship design, and the benefits these technologies will have in future Expeditionary Logistics.

1. Hybrid Linear Actuator

The actuator will combine a set of magnetostrictive thrusters with either a tubular linear induction motor or a linear synchronous motor (LSM) that could replace hydraulic cylinders or electric motors in cargo handling gear such as ordnance and cargo elevators, and conveyor belts. Figure 11 is ONR's representation of a Linear Actuator.

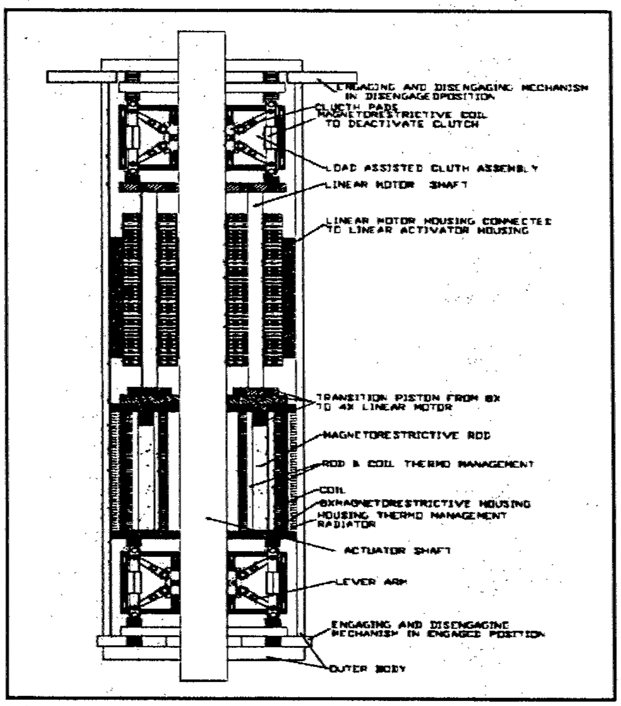


Figure 11. Linear Actuator (Source: ONR)

Potential benefits

- Potential for weight, space and power savings.
- Potential to improve many cargo handling systems by replacing hydraulic or electric motors.
- Reduced maintenance, particularly specialized (fluid system)
- Repair personnel.
- Supports electric ship initiatives.

2. Linear Electric Drive Technology

This technology will be incorporated to horizontal/vertical cargo movement systems powered by Linear Induction Motor (LIM) technology. This is an extension of a previous SBIR. Technology development includes a prime mover, breaking and control system for the conveyor. The system allows automatic transition between

horizontal and vertical movements. Some of the goals ONR has set for this technology are listed below.

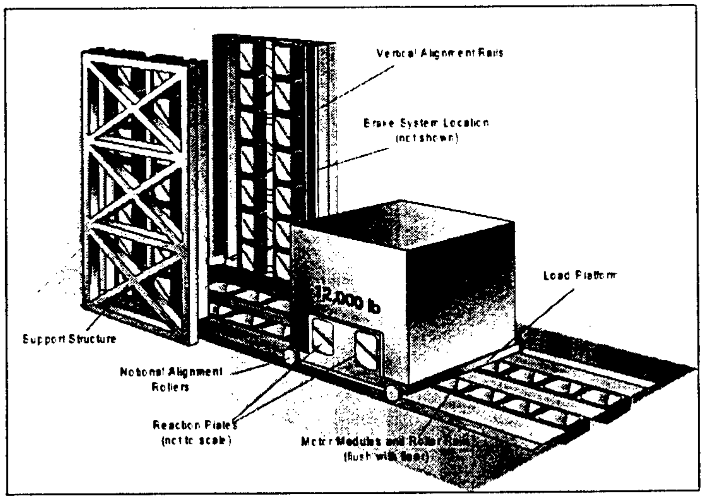


Figure 12. Vertical/Horizontal LIM Conveyor Belt (Source: ONR)

Potential benefits

- Handling Naval packing up to 12,000 lbs.
- 30 % workload reduction over current systems.
- 20 % weight reduction.
- 20 % power consumption reduction.
- Reduced Workload due to robotics and system controls.
- Improved integration ability since vertical movement trunks do not need to be perfectly vertical and follow hull contours.
- Increased throughput speed resulting from ability to handle larger loads.

3. *Omni Directional Vehicle*

The omni-directional vehicle married to a forklift type operation is capable of motion in any direction and could rotate within its own footprint. It will have an intelligent control and navigation system that allows it to autonomously travel between deck stations and a hold.

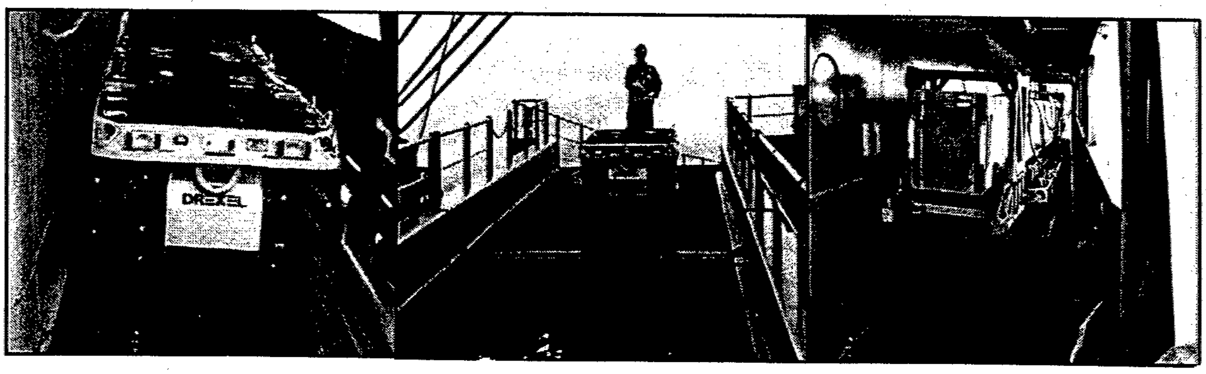


Figure 13. Omni Directional Vehicle (Source: NAVSEA)

Potential benefits

- Handle Naval packing up to 12,000 lbs.
- Throughput of 414 pallet and 100 QUADCONS in 6 hrs.
- 50 % manning reduction.
- 50 % power consumption reduction.
- 50 % weight and volume reduction.
- Reduced Workload due to robotics and system controls allowing autonomous navigation.
- Omni-Directional motion has less arrangement impact than forklifts by eliminating turning areas.
- Potential for reduced maintenance over forklift trucks.

- Will carry larger loads than forklifts but have a smaller footprint.

4. Advanced Weapons Elevator

This new weapons elevator and ballistic elevator shaft cargo hatch for aircraft carrier-type weapons elevators will improve weapons handling rates with reduced maintenance and enhanced utilization flexibility. The primary technology is a spindle screw actuator with condition-based maintenance built in. The system includes a new, faster ballistic hatch and a highly dexterous mobile elevator carriage.

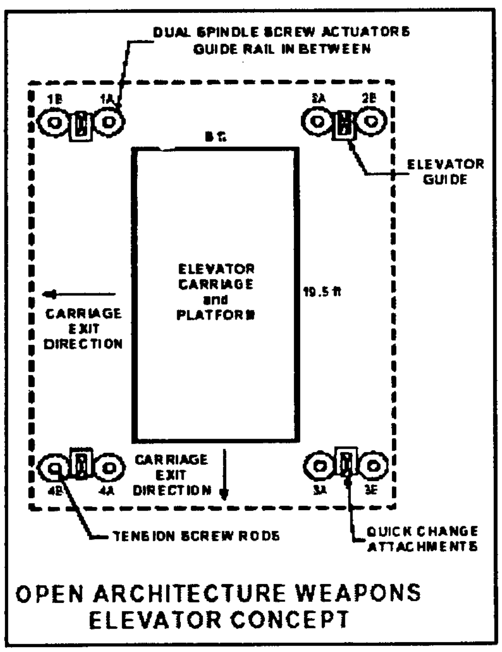


Figure 14. , Advance Weapons Elevator (Source: ONR)

Potential benefits

- 30 % workload reduction.
- 20 % weight reduction over current elevators.

- 20 % power consumption reduction.
- 100 % redundant system.
- Increased aircraft sortie rates.
- Improve elevator shaft utilization by a factor of 5.
- Enhanced utilization flexibility.
- Potential for increased reliability and reduced maintenance.

5. Automated Magazine

In support of the NAVSTORS automated magazine, two high-risk components - the Standard Payload Interface (SPI) and Robotic Pallet Carriers - will be developed. SPIs provide common grasping interface and automatically secure cargo for transit. Payload Carriers are powered, robotic sleds that automatically move loads around the magazine.

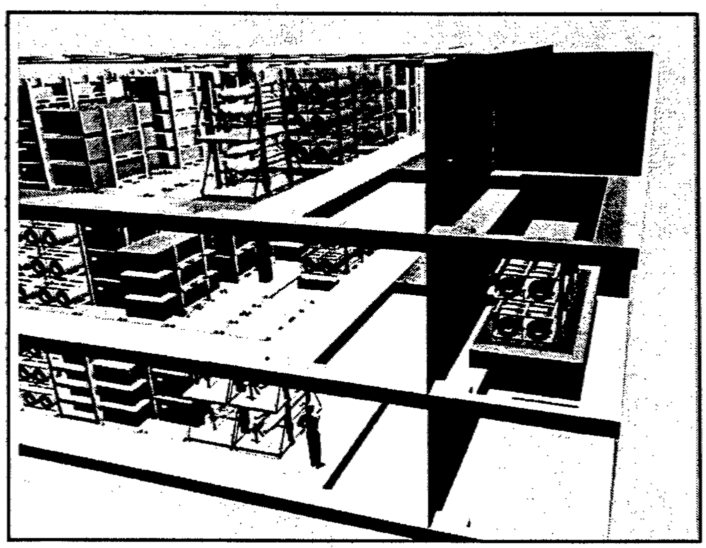


Figure 15. Automated Magazine (Source: NAVSEA)

Potential benefits

- Handle Naval packing up to 12,000 lbs.
- Selective off load
- Operate continuously on 15° heel, and maintain load control on 30° heel.
- A Universal Handling Platform is required for dramatic
- Improvement in cargo handling.
- Interface with NAVSTORS automated handling systems.
- Enables Selective Offload of magazines and holds.

6. Automated Stowage and Retrieval System

The ASRS system would automate storerooms, holds and magazines and would allow for selective offload of pallets or containers. Loads would automatically be locked into stowage during Strike-Down and unlocked for Strike-Up.

Potential benefits

- Handle Naval packing up to 12,000 lbs.
- Throughput of 414 pallet and 100 QUADCONS in 6 hrs.
- Operate continuously on 15° heel, and maintain load control on 30° heel.
- 75 % manning reduction.

- Selective off load
- Reduced Workload due to robotics and system controls.
- Selective offload to the package (nominally pallet) load.
- Increased throughput speed resulting from ability to handle larger loads.

7. *Motion Compensated Crane*

In its normal mode of operations, the motion compensated crane is extended transversely from the warehouse and is expected standard container loads at sea state 4 with an estimated throughput expected to at 29 TEUs per hour. The ability of the crane to be recessed into the warehouse when not in used and to operate with minimal intrusion into the flight space above, makes it well suited for the ship design.

Potential benefits

- Handle containerized cargo up to 24,000 lbs.
- Throughput of 29 ISO container per hour.
- Operate continuously up to sea state 4.
- Reduced Workload due to robotics and system controls.
- Selective on-load due to transverse motion of crane over delivery ship.
- Increased throughput speed resulting from ability to handle larger loads.

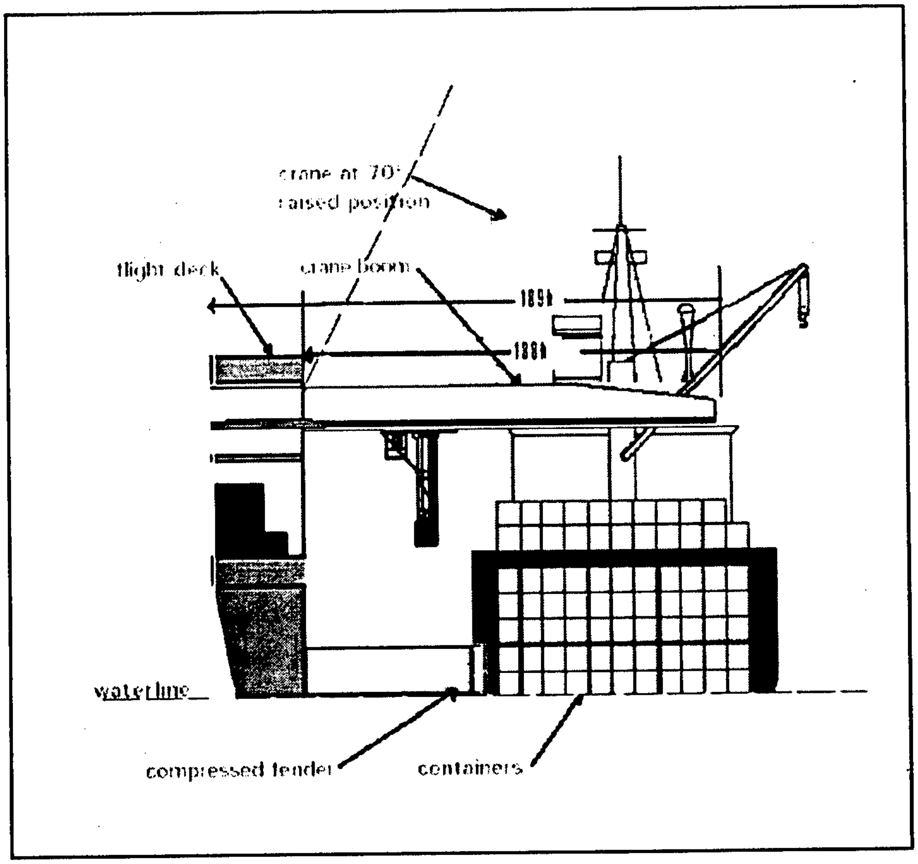


Figure 16. Motion Compensated Crane (Source: NIST)

3. Propulsion

1. Propulsion Plant Trade off Studies

The considerations for the propulsion plant are minimizing the weight and the size, cost of the construction and overhaul, fuel efficiency, endurance, maintenance, modularity and location flexibility, manning, resistance to vibration and shock, easy and quick start up times and reliability. All possible marine propulsion plant types were researched. All the studies were held parallel to Operational Requirement Document.

The researched marine plants are conventional steam plant, nuclear steam plant, diesel, gas turbine and the fuel cell. These systems are compared with respect to the design consideration mentioned above.

Conventional Steam Plant: The conventional steam plant is most efficient for different loading conditions and low speed. High power is also available most of the time. Another advantage is the ability to use the steam for the auxiliary systems. In addition, it is really easy to start up, but requires a high volume and weight. The fuel efficiency is low. So this brings up high volume requirement for the fuel storage. Manning and the maintenance is also a problem, it needs long overhaul time and requires huge amount of manning. According to design considerations the steam propulsion plant was not found to be the appropriate plant for the design.

Nuclear Steam Plant: The most important advantage of the nuclear plant is its high endurance. It is not needed to refuel repeated times compared to other systems. It doesn't need air for combustion. Since one of the most important missions of the designed ship is air operation, this system enables much more fuel storage for the aviation assets. But it is the one most cost inefficient. It also requires high manning and personnel training in service and during overhaul period. Another disadvantage of this system is weight because of the shielding. Radiation, long start up time and political problems due to nuclear plant are other disadvantages. The all the information about the nuclear plants is classified, so the design team couldn't get the satisfactory results from their research. When the advantages and the disadvantages of the nuclear plant are weighed, it was decided that this type of propulsion system is not feasible for the design.

Diesel Engines: Even though the diesel engines are cost efficient and have low specific fuel consumption, because of its high weight requirements and high lube oil consumption it was

out of the design. Diesel systems have space and arrangement problems due to need of several engines per shaft. The number of engines, which will be used to meet the power requirement, will add a lot to volume and weight. So the diesel engines were dropped from the design.

Fuel Cells: The fuel cells have very good advantages but the power is really a big problem. Even its efficient, modular design, fuel flexibility, and combustion less and pollution free source of power, the current technology can't give enough energy to the designed ship. Even if it is used with a gas turbine it is still far away from the range of the design.

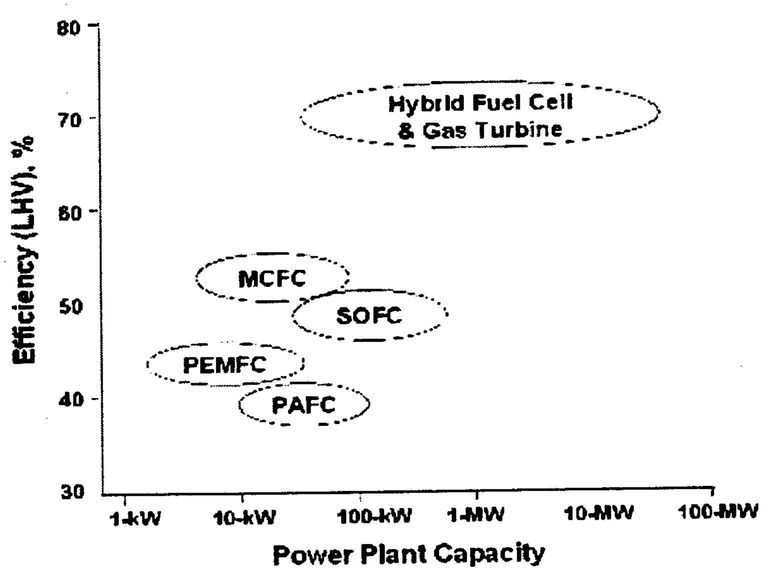


Figure 17. Fuel Cell Power Capacity

Gas Turbines: The advantages of the gas turbines are lightweight, low specific fuel consumption at high speeds, modularity and location flexibility, quietness, reliability and easy start up time. Maintenance and manning can be added to those mentioned above. The main disadvantage was seen to be due to large intake and exhaust ducts. This will be a bad issue for volume and NBC problem. But it was decided that these advantages

could be lowered by adjustments to the design and propulsion plant. The high SFC for the low speeds and high unit cost is another disadvantage.

2. Gas Turbine Comparisons

MT30: With 36 MW of total power, MT 30 was another choice for the propulsion plant. It has a thermal efficiency of more than 40 %. The SFC of this engine is even efficient while operating at 70% of full power. Even though it has a small weight; it has almost three times more volume than the LM 6000. To achieve the full power of the ship, 5 MT30 must be utilized. In this case volume requirement for the machinery room will increase dramatically therefore this type of engine is not feasible for the design.

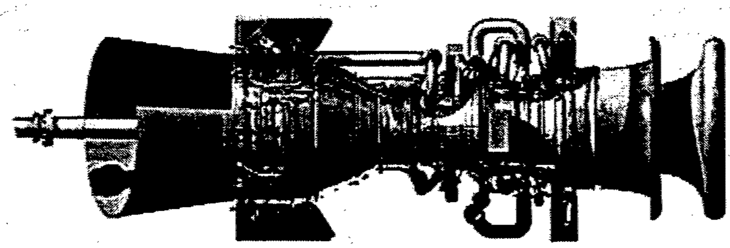


Figure 18. MT 30 Gas Turbine

ICR WR21: This gas turbine can save fuel by utilizing the intercooling technology. Its annual fuel saving is in the range of 14% to 25% depending on the ship's mission. But its weight is the leading disadvantage. The ship will need 6 of these engines to get the required full power and only its weight pushes it out of the design.

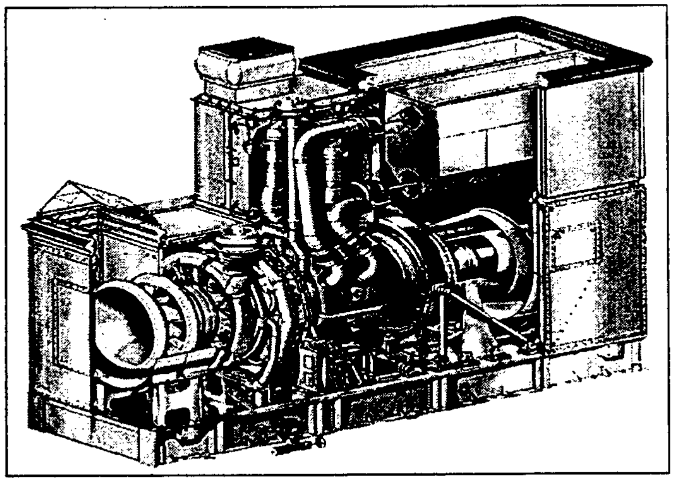


Figure 19. ICR W21 Gas Turbine

LM2500: This engine has a variety of uses in marine applications. It uses the latest power plant technology. It gives great flexibility for cogeneration and combined cycle applications. Ability to use the exhaust gas to produce heat increases the overall efficiency. This steam can be used for auxiliary systems like boilers and other equipments. The LM 2500 has an availability rate of 99.6 %. Engines need corrective maintenance of 40 hours in every 10,000 hours. The hot section maintenance is done in every period of 12 000 to 15 000 hours. LM 2500 was taken into account for ship service and loitering speeds. But, it was decided that; because of its low power with respect to power requirement of the ship and the high SFC it is not the engine for the design. Compared to its advanced model LM 2500+, even it weighs is 10% less, it has almost 90% more volume due to its width.

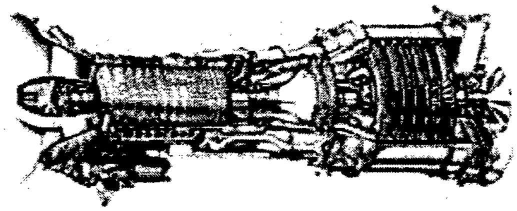


Figure 20. LM 2500 Gas Turbine

LM2500+: This engine is the newest technology and newest aeroderivative design of the GE Company. It is the advanced model of the LM 2500. It delivers 25 % more power than LM 2500. Availability rate of the LM 2500+ is again 99.6 %. Reliability, high efficiency, low SFC, installation flexibility makes it one of the most demanded engine in the market of marine applications. It has simple cycle thermal efficiency of 39% at ISO conditions. The LM2500+ achieves increased power over the LM2500 primarily by increasing the compressor airflow 23%, with a minimal increase in combustor firing temperature by adding a compression stage (zero stage) to the front of the LM2500 compressor. The temperature capability of the hot section was also increased by adding a thermal barrier coating to the combustor, upgrading turbine airfoil materials and by improving internal cooling designs. The designed ship will need 15 MW of daily electric power. Lm 2500+ is chosen for loitering speeds. With only one LM 2500+, the 24-hour electric load and up to 14 knots loitering speed can be achieved.

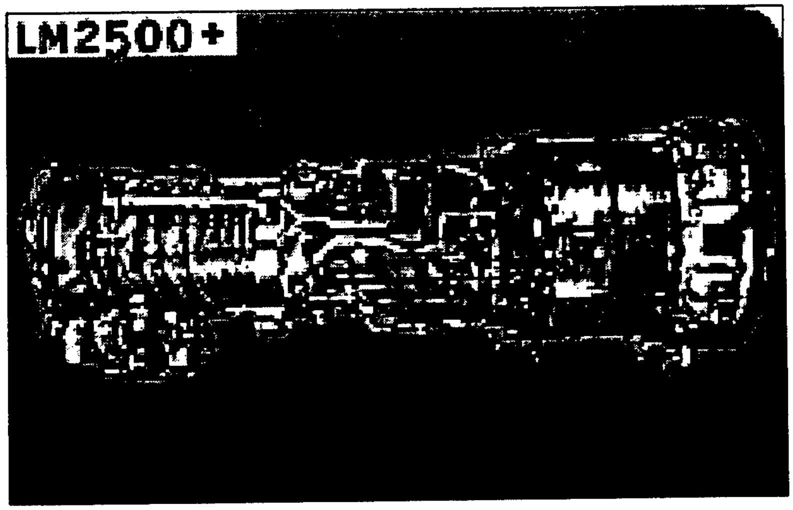


Figure 21. LM 2500+ Gas Turbine

LM 1600: LM 1600 is another aero derivative engine of the LM series, which is derived from F404 turbofan aircraft engine. It is fairly small engine for the design. It has been taken into account for the trade off studies for 20 days of stationary position of the ship, providing only electrical load. The comparison was made with LM 2500+. The designed ship's electric load is 15 MW, which is maximum power for LM 1600. So in order to feed the ship for the electric load the LM 1600 must be run in full power, where Lm 2500+ must be run in half power. It gives only 10% fuel saving compared to LM 2500+. So it is dropped from consideration. It was not seen feasible to have another type of engine for only 10 percent of fuel saving in 20 days.

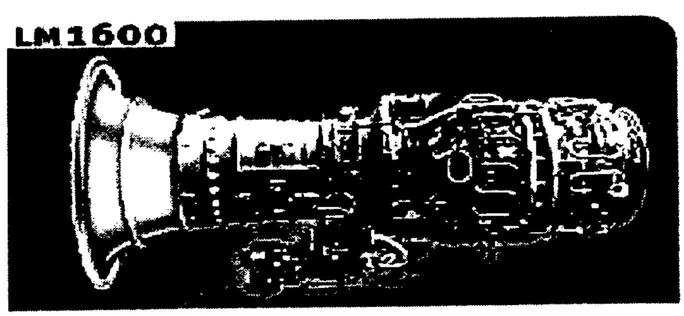


Figure 22. LM 1600 Gas Turbine

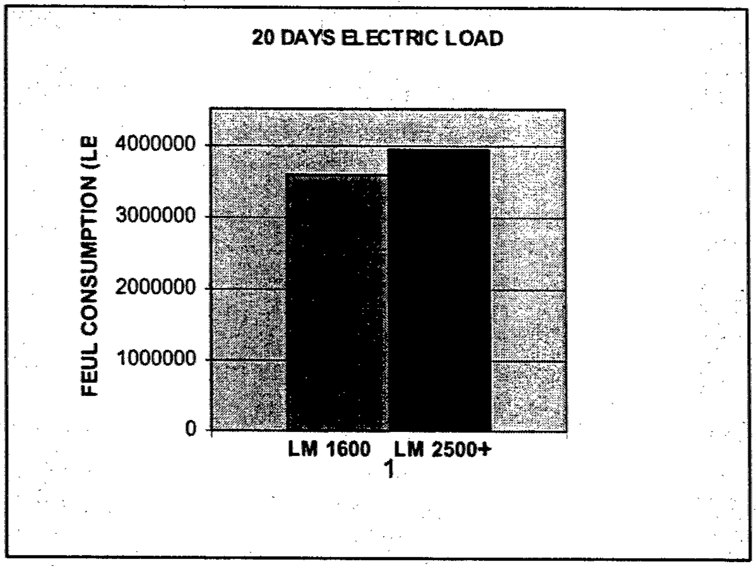


Figure 23. LM 2500+ & LM 1600 Fuel Consumption Comparison For 20 Days Of Electrical Load

LM6000: The LM6000 is the most fuel-efficient simple-cycle gas turbine in its size class today. It delivers 57330 HP with a thermal efficiency over 40%. It provides the power and unprecedented efficiency needed by users at an installed cost that is competitive with any gas turbine. It is usually being used most efficiently with the cargo and fast ferry ships in marine applications. It is also an aero derivative, derived from the CF6-80C2 commercial aircraft engine. Its corrosion resistant material and coatings provide maximum parts life and reliability.

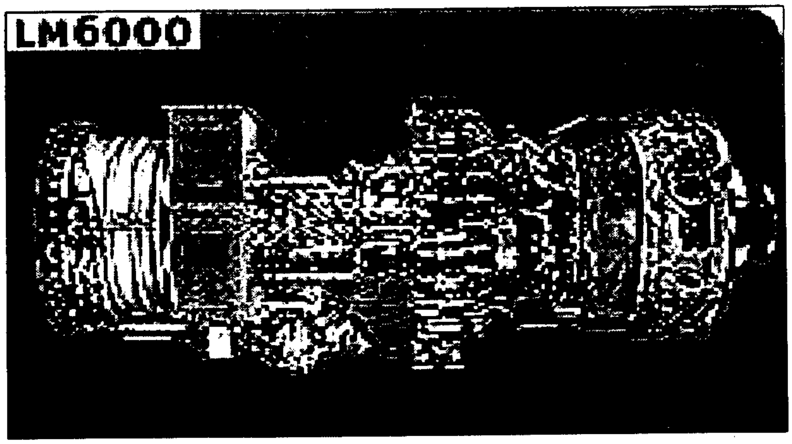


Figure 24. LM 6000 Gas Turbine

GAS TURBINES	power (MW)	power (SHP)	SFC	length (ft)	width(ft)	height (ft)	volume (ft^3)	Weight (Lb)
LM6000	42.75	57330	0.329	24.0	7.0	8.3	1394.4	18010.0
LM2500+	30.11	40500	0.354	22.0	8.7	6.7	1280.9	11545.0
LM2500	25.06	33600	0.373	21.4	15.7	6.7	2246.7	10300.0
WR 21	25.24	33850	0.337	26.3	8.7	15.8	3602.7	12000.0
MT30	36.00	48273	0.346	30.0	12.0	14.7	5292.0	13668.6
LM 1600	14.92	20008	0.376	13.8	10.0	6.67	923.1	8200.0

Table 12. Gas Turbine Comparisons

The designed ship will need power over 218 000 HP with the 24 hour electrical load. Six types of gas turbine engines were discussed. Each of them was considered with respect to dimensions, weight, volume, fuel efficiency, and maximum power. It was decided that the most feasible prime movers for the design are LM 6000 and the LM 2500+. To get the power needed by the ship, six LM 2500+ or four LM 6000 or three LM 6000 and one LM 2500+ is needed. With the choice of six LM 2500+ and four LM 6000 we will have excess power. The designed ship will not need speeds higher than 30 knots according to ORD. So the most feasible design for the propulsion plant is three LM 6000 and one LM 2500+.

If LM 6000 is used for loitering speeds instead of LM 2500+, over the period of a month 323 LT more fuel will be needed due to specific fuel consumption rates, besides there will be excess power, more volume and more weight. It seems the LM 2500+ gives better fuel consumption in low speeds compared to LM 6000.

LM 2500+ performs very inefficiently between 15 and 17 knots. The SFC for the LM 2500+ is efficient only up to 9 knots. LM 6000 has smaller SFC for the speeds higher than 10 knots.

As a conclusion for the propulsion plant three LM 6000 and one LM 2500+ will be used in the design. The LM 2500+ will be utilized for the daily electric load and loitering up to 10 knots. LM 6000 will be used for the higher speeds and combat system requirements.

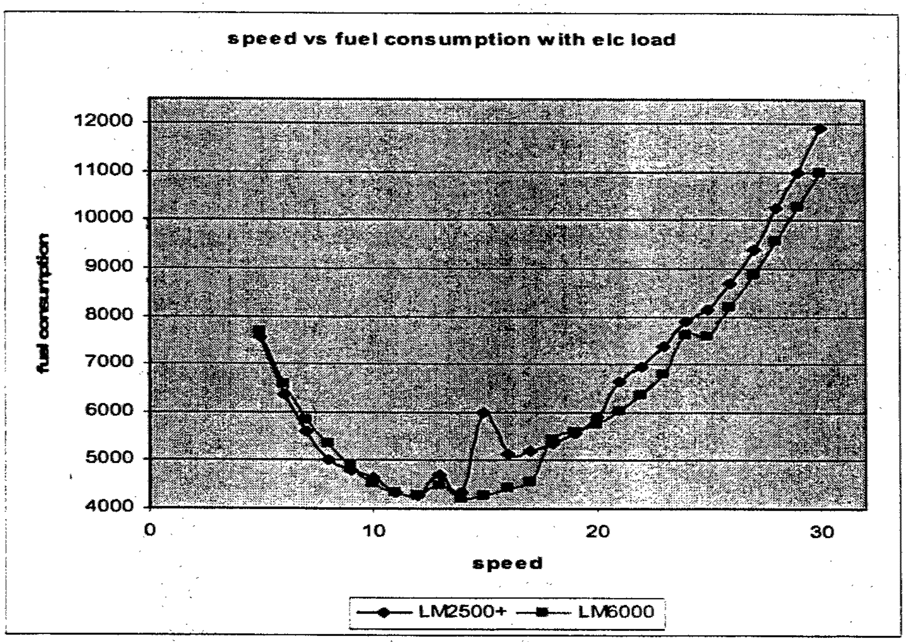


Figure 25. Speed versus Fuel Consumption Comparison Between LM 2500+ & LM 6000

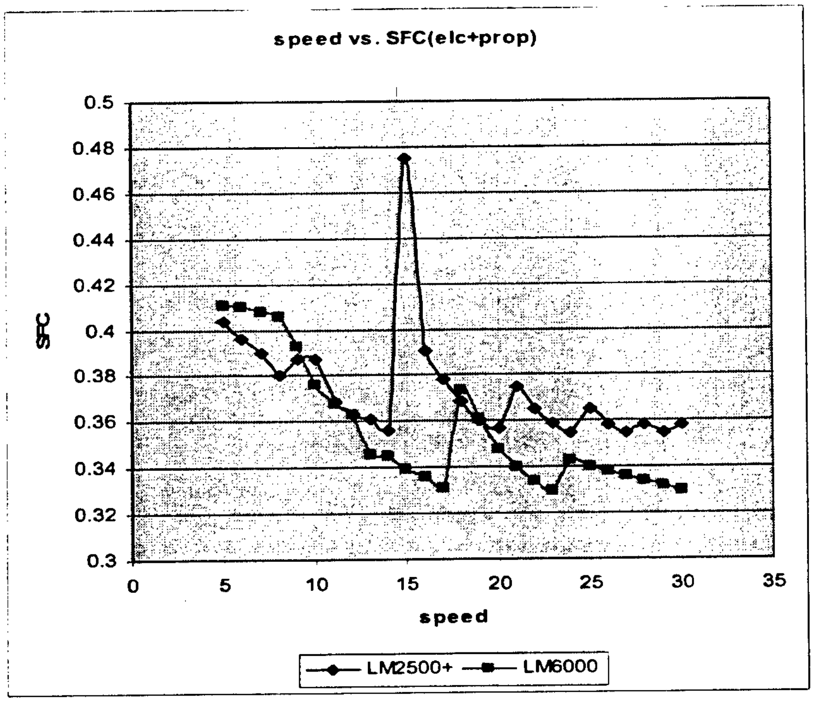
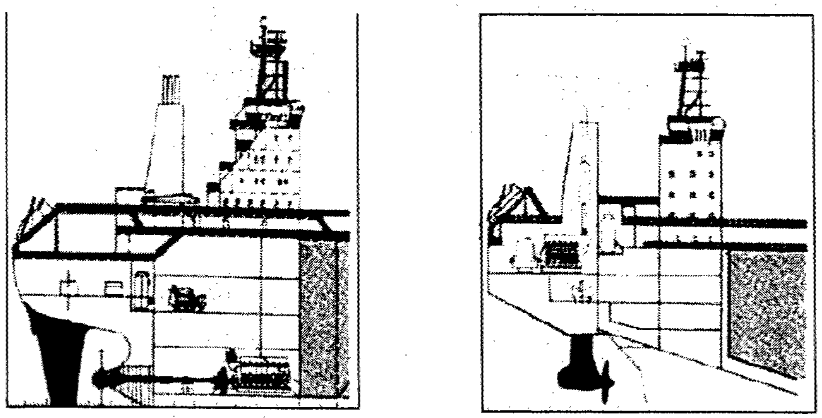


Figure 26. Speed versus SFC Comparison Between LM 2500+ & LM 6000

3. *Propulsors*

Two technologies were taken into account for the trade off studies of propulsors. These are propellers and electrical pods. Since there is no high-speed requirement for the design water jets and the hydro drives are kept out of consideration. Another disadvantage of the water jets is the weight problem. The water entering the duct increases the weight of the ship. When the speed of the designed ship is considered even hydro drives cannot get rid of the water, which causes the weight problem.

The main comparison and discussion was made between pods and the conventional propellers. The figure below compares two systems on an arctic tanker type ship.



with Podded Propulsor

Figure 27. Conventional Propulsion System and Electrical Podded Propulsion System Comparison

The main engines are co-located with the propulsion motors whose positions and installation angles are derived from the shaft design and location. Long shafts bring high cost and distribution of the wake field with it. If the shaft line is shortened, then the angle of the shaft line increases. Location and arrangement of the pods give great flexibility to designers. There is no problem of positioning for the shafts, propulsion motors and the prime movers. The pods also give location flexibility for the machinery room arrangements.

Elimination of the shaft lines and the stern thruster gives weight reduction for the design. The only disadvantage of the pods in terms of spacing is; they save space in the lower decks but they need more area in the deck above the pod, because the turning, cooling and the power supply equipments occupy more than the conventional rudder machinery room.

The ship is more maneuverable with the pods. It is predicted that, docking times can be reduced by 20 %. The use of the pods eliminates the stern thrusters. But at the same time it increases the forces, which can be generated during low speed maneuverings. In addition to that; in most situations large

forces can be generated in the aft of the ship during crabbing operations due to large installed power of the pods. The disadvantage of the pods in maneuvering is the inefficient operation with high speeds compared to rudders. In today's technology designers are studying steerable flaps connected to the pod for course keeping at high speeds. By the year of 2020 this it is expected that this disadvantage of the pods will be overcome.

Material cost of the pods is relatively high. Because the pod unit has lots of propulsion system parts in it. But on the other hand compact design of the pod reduces the overall material and installation cost. The repair and test of the podded drive can be done separately in the workshops of the shipyards. This increases the repair and test efficiency of the pods compared the work done on the board.

After weighing the advantages and the disadvantages of the two propulsion systems the design team decided to use pods for the propulsors.

4. Propulsor Motor Selection

The propulsor motor selection trade off studies were made among HTS AC synchronous motors, conventional motors and DC Homopolar motors. The AC synchronous motor and the DC Homopolar motor are superconducting motors, which are being demonstrated by ONR. Table 13 below shows the comparison between superconducting technology and conventional systems.

Superconducting Electric Power Applications	System Performance	Reliability & Maintenance	Efficiency	Operating Lifetime	Installed Cost [1]	Competing Technology
AC synchronous generators	Improved steady state and transient	Must be equivalent	Higher by 0.5-1.0%	Longer	Equal or higher	Gaseous and liquid-cooled
AC synchronous motors	No change	Must be equivalent	Higher by 1.0 to 2.0%	Longer	Higher	Induction and addition of VSD
AC underground transmission	Ability to double the rated capacity	Must be equivalent to conven. undrgd.	Slightly higher	Longer	Higher	• Cu/Al • "FACTS" • extruded
Fault-Current Limiters for transmission & distribution	Reduces transient currents on system components	Comparable to circuit breakers	More efficient T & D system	Longer than circuit breakers	2 to 10x circuit breaker	• Solid State breakers • Reactors • "FACTS"
Transformers for transmission & distribution	No change [2]	Must be equivalent to conven. transf.	Slightly higher by 0.1-0.2% [3]	Longer	Higher	• Iron Core
Storage Superconducting Magnetic Energy Storage (SMES)	Improves power quality and conditioning, spinning reserve, VAR & AGC	Comparable to other T&D components	Most efficient storage technology	Longer	Higher	• Flywheels • VAR Comp. • Batteries • STATCOM • Capacitors

Table 13. Comparison of Superconducting Electric Power Applications to Conventional Technologies

As seen in the table the superconducting technology increases the system performance. There is no loss for reliability and the maintenance and they have longer operating lifetime. Even with these kinds of improvements they don't have a significant change for the efficiency. The only disadvantage from the table is the cost. The size and the power density of the conventional motors are far away from our requirements. Since the pods are chosen for the propulsors, the dimensions of the motors are very important. The ship will need large amounts of power for propulsion. This will increase the number of the pods that will be utilized. This is one of the reasons for the need for small size propulsion motors.

The other reason for the restriction of the motors size is the narrow main hull of the trimaran design. In order to install the pods in an efficient way we need to have smaller pods than today. It seems that only superconducting motor technology meets our requirements.

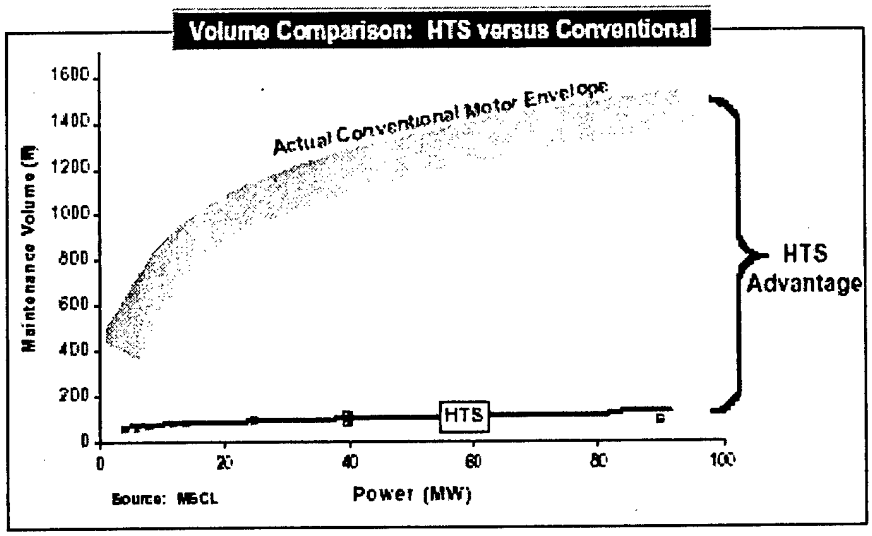


Figure 28. Volume Comparison HTS versus Conventional

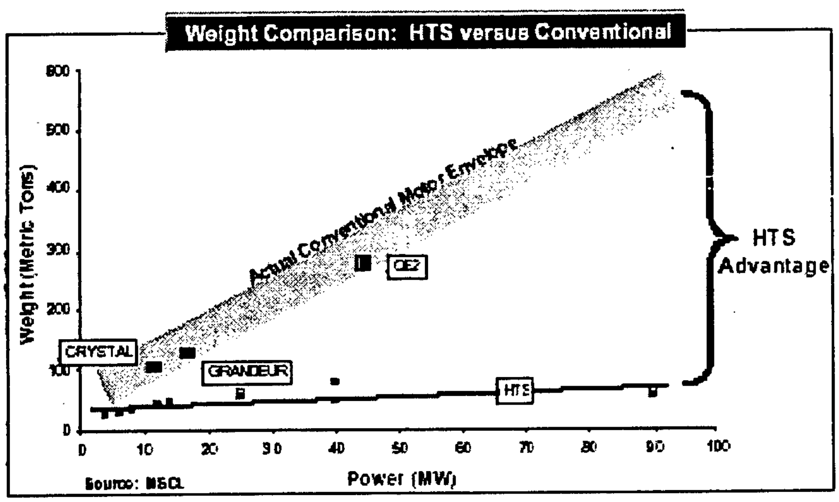


Figure 29. Weight Comparison HTS versus Conventional

Besides the volume advantages; the HTS (High Temperature Superconducting) also gives a huge amount of weight advantage even for power levels up to 90 MW it weighs less than 100 tons.

In terms of motor efficiency the HTS has again overwhelming advantages compared to the other type motors.

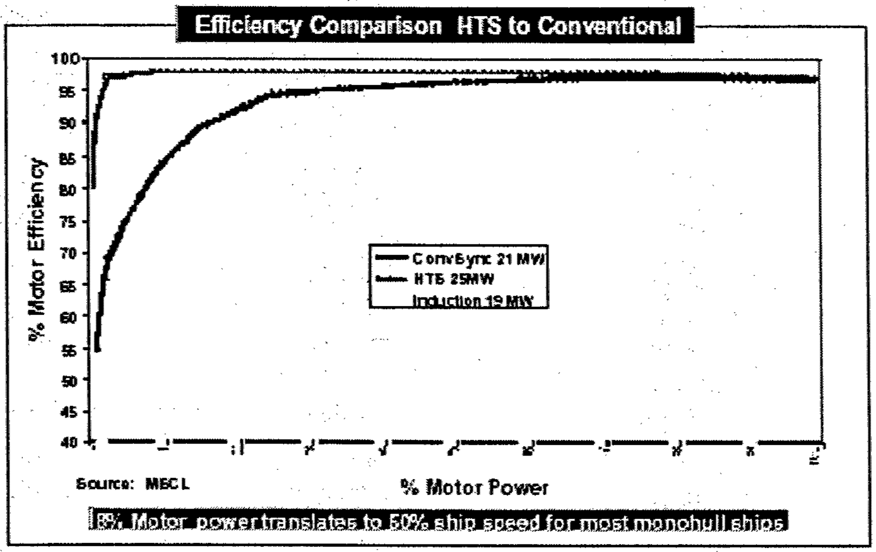


Figure 30. Efficiency Comparison HTS to Conventional

After comparing the conventional motors with the superconducting motors, DC superconducting homopolar and HTS AC Synchronous motor were considered.

DC Superconducting Homopolar Motor: For warship propulsion R&D, the Navy built a 25,000 hp multipole induction motor that weights in at 117 tons and occupies 2500 ft^3. In comparison, and yet to be built, a 40,000 hp superconducting DC homopolar (SCDCHP) motor would weigh in at 33 tons and occupy 1250 ft^3. But this motor will need two cryo-coolers. These coolers will weigh less than 200Lbs. Since it creates low noise, it is very stealthy.

High Temperature Superconducting (HTS) AC Synchronous Motor: American Superconductors Company is working on 33 500 Hp synchronous motor for the navy. The motor includes all the

cooling systems and has one fifth of the size and one third of the weight of a conventional electric motor of the same power rating. It provides great hydrodynamic efficiency for the pods with its dimensions. The Motor can be driven at several times

Motor Type	Diameter (m)	Length (m)	Cyro-cooler Volume (m^3)
HTS AC synchronous	2.65	2.08	1.0
DC Homopolar	2.65	3.05	1.4

Table 14. HTS AC Synchronous versus DC Homopolar Motor Dimension Comparison

the rated output for short periods, providing the ship with important operational capability. The motor can be turned off in case of a fault in the stator. This ability gives motor field control. They have low noise and no cogging torque. These motors are smaller than the DC Homopolar motors.

As a conclusion HTS AC Synchronous motors were chosen for the propulsor motors.

4. Combat Systems

The Sea Force will require cutting edge technology for the Year 2020 to be successful. Every aspect of the ship will have to be state-of-the-art to ensure the ship can be designed as envisioned. While it will not be possible to discuss every technological leap that must be made, some of the major technical hurdles will be described below. These areas include: power generation greater than 100 Megawatts for use with the Free Electron Laser and Rail Gun, Unmanned Undersea Vehicles to

support next generation mine and undersea warfare, and C4ISR capabilities that help support implementation of the Sea Force as a Joint Command Center.

Assuming that the significant technical challenges still ahead for implementing a 1 MW Free Electron Laser and Rail Gun are solved, there will still be a power generation requirement on the order of 100+ Megawatts. The major issues with generating this amount of power on a ship lie in the design of the propulsion and electrical system, storage of the required power for nearly instantaneous distribution, and the control of heat dissipation in these power systems.

The foundation of these weapon systems is the ability to operate using high levels of peak power. Current ships do not have the ability to generate even a quarter of the power necessary to operate directed energy weapons. Currently, ships utilize propulsion and electric systems that are separate. On a DDG-51 class ship, the propulsion system generates 80-100 MW of power. The electrical system is only capable of generating 7.5 MW of power. For each FEL director, about 10 MW of power will be required to have an output of 1.5 MW. Each rail gun can require up to 60 MW depending on the desired range. Clearly, an electrical system is required with a drastically increases output. The first step in this process will be to implement an Integrated Power System or IPS. Unlike current systems that only allow the propulsion power to be directed into the propellers, an IPS will allow unused propulsion power to be utilized on other systems such as the FEL and Rail Gun [25].

In conjunction with the IPS, a power storage system capable of generating high peak power and then being recharged quickly is required. The two most promising technologies in this area are capacitor banks and high power rotating generators or flywheels. These energy storage mechanisms are the most

feasible means of meeting the FEL and Rail Gun powering requirements on board Sea Force.

To provide the necessary power to operate a rail gun, about 60-200 MJ of energy must be output in a time of about 8ms. One option for providing this type of power is a capacitor bank. This type of power output will allow the rail gun a firing rate of about 6 rounds per minute. The construction of the power banks will involve linking modules of capacitors together in parallel. One system under analysis involves building a module of capacitors capable of storing 2.5 MJ of energy and then linking 25 of these modules together in parallel to give an output of about 60 MJ [26].

The other option for powering the FEL and Rail Gun will be either a compulsator (high-power rotating generator) or a flywheel. The rotating machine within the generator is different from conventional flywheels because it is made of carbon-fiber composite structures that can be operated at stress levels up to 2.8 Gpa (400 kpsi). Currently, these generators can generate between 20 and 30 MJ and should be capable of storing up to 200 MJ and delivering power in excess of 10 GW by the year 2020.

For the FEL, which requires a lower peak power output with a much longer pulse (on the order of seconds), a flywheel option could be used. The flywheel is similar to the high power-rotating generator, but it generates a much lower peak power output in exchange for a much longer pulse of power. In addition to providing a better power source for the Free Electron Laser, the lower power output allows greater flexibility in the design of the flywheel [27].

A final key to the successful implementation of these directed energy weapons will be thermal management. While it appears all of the previously discussed power generation

techniques may be viable, the system that succeeds will most likely be the one which is able to dissipate heat the most rapidly. The ability to quite literally avoid catching on fire as well as the ability to provide the necessary power requirements in a compact design will be the key to success. While thermal management and heat dissipation are very important aspects of this system, the subjects are addressed in more detail in Shiffler (2001) [28].

Another excellent capability that will be enabled by future technology is that of Unmanned Undersea Vehicles for both hydrographic reconnaissance and mine warfare missions. Currently, there is significant research being done to incorporate undersea vehicles in multiple vehicle systems to survey the littoral environment [29]. Additionally, the LMRS (Long Term Mine Reconnaissance System) system under design uses underwater vehicles that are launched and recovered through torpedo tubes using a mechanical arm as seen in the figure below:

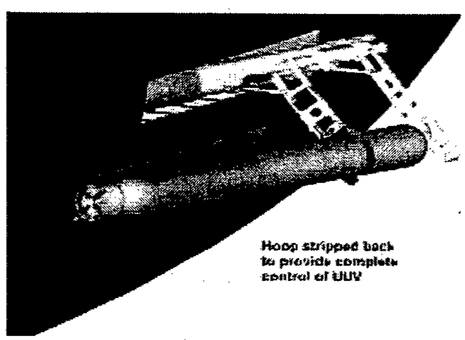


Figure 31. Torpedo Tube Recovery of UUV

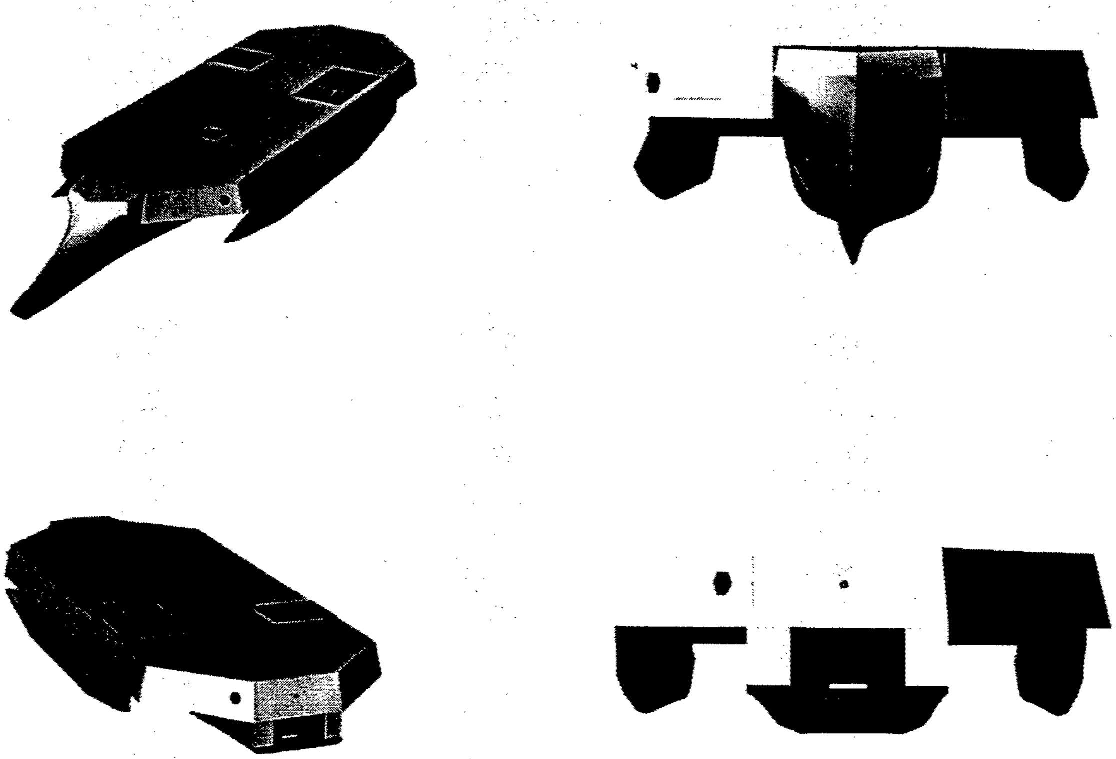
While the LMRS program is being designed for use in submarines, the technology could easily be incorporated into a surface ship design as well. Programs such as SAHRV (Semi-Autonomous Hydrographic Reconnaissance Vehicle) and RMS (Remote Minehunting System) are under research and development for surface ship use

[30&31]. The underwater vehicle used in this project is the REMUS (Remote Environmental Measuring UnitS) vehicle. While the underwater world is full of unknowns, potential threats and counter activities for UUV success, it will be necessary to design systems that as capable as any human in the same role. One of the most important capabilities is in the are of obstacle avoidance. For a thorough assessment and solution to this problem for the REMUS vehicle, see Fodrea (2002) [32].

Remote Mine Hunting systems provide excellent capabilities in Undersea Warfare using aircraft mounted sensors such as Airborne Laser Mine Detection System or ALMDS. With the improvements in laser technology over the past several years, electro-optics technologies using blue-green lasers has become a potential method of locating sea mines. Lasers have become more powerful and compact and their wavelengths more tunable. The blue-green laser uses a frequency compatible with seawater, allowing Laser Detection and Ranging (LIDAR) to provide accurate information on the characteristics of targets at various water depths. The system is being designed for both self-protection when traveling through choke points and confined straits, as well as rapid reconnaissance of minefields in support of amphibious operations. The Airborne Laser Mine Detection System (ALMDS) is an electro-optics-based mine reconnaissance system that will detect and localize drifting/floating and shallow-water moored mines from the CH-60 or similar helicopter platform. ALMDS IOC is planned for FY05.

V. SHIP'S DESCRIPTORS

Before we proceed with a more detailed description of the ship's characteristics, we present here a few drawings of the final selection. The remaining sections of this chapter describe the rationale for selecting the hull form and present an outline of our calculations.



A. NAVAL ARCHITECTURE CURVES

1. Hull Type Selection

The hull design process started with the creation of a list of requirements for the hull. These requirements were derived from the Analysis of Alternatives phase of this project. The major design characteristics for the Sea Force Ship were as follows:

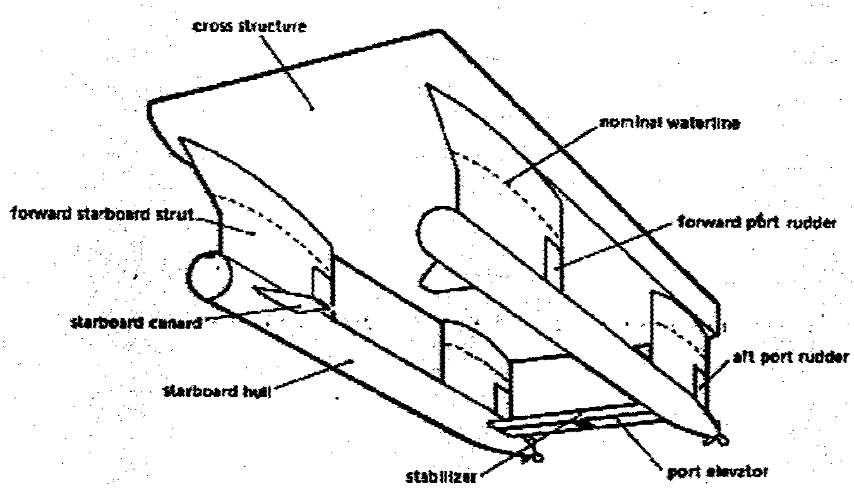
- Large flight deck.
- Relatively high speed (25-30 kts).
- Internal well deck with the ability to accommodate LCACs and LCUs.
- Stable enough to conduct operations in sea state 3 without difficulty, preferable up to sea state 5.
- Large cargo capacity for the storage of Marines, vehicles and supplies needed for amphibious operation.

With these requirements in mind, an analysis of different hull forms was conducted. The following hull forms were evaluated:

- SWATH (Small Waterplane Area Twin Hull)
- Hydrofoil
- Surface Effect
- Monohull
- Multi-hull

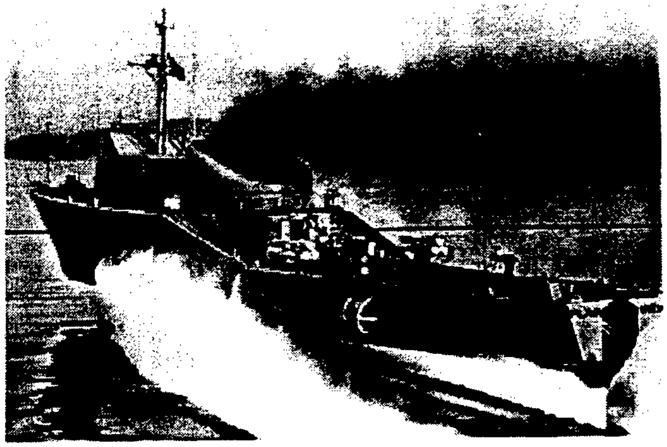
SWATH (Small Waterplane Area, Twin Hull) hull designs provide stability and a large deck suitable for a large flight deck. The small waterline area of the SWATH design is achieved by using submerged torpedo-like hulls that are connected to the

upper part of the ship with very thin struts. These thin struts have extremely large length-to-beam ratios, and so the ship produces very little wave action, making this hull form extremely efficient. A typical SWATH hull diagram is shown below.



Unfortunately, these thin struts are not wide enough to incorporate a well-deck into the design, which was something that was needed. So the SWATH design was not further considered.

The main advantage to a hydrofoil hull form is speed. They are extremely fast, but they also use a lot of fuel because of their high power requirements. One of the largest hydrofoils ever built was the USS PLANEVIEW shown in the following picture.



It was built in the 1960s, and was only 320 tons. The Soviet Union also built one of a similar size, but neither design proved large hydrofoils to be worth pursuing in future ships. No research could be found about future development of large hydrofoils, indicating that the design is not predicted to be viable for large transport ships in the near future. Because of the hydrofoil's high requirements for power, the enginroom size and required fuel capacity for the Sea Force Ship was projected to be immense, reducing it's cargo carrying ability, and thus this ship hull form was also rejected.

Speed is also a primary advantage of the Surface Effect hull design. Although more suited for application to the Sea Force Ship than a hydrofoil, this hull form is also usually reserved for high speed vessels, which the Sea Force Ship was not required to be. Because these hulls require quite a bit more power than a normal monuhull, and since speed was not a critical factor in the design of this ship, this hull factor was not given further consideration.

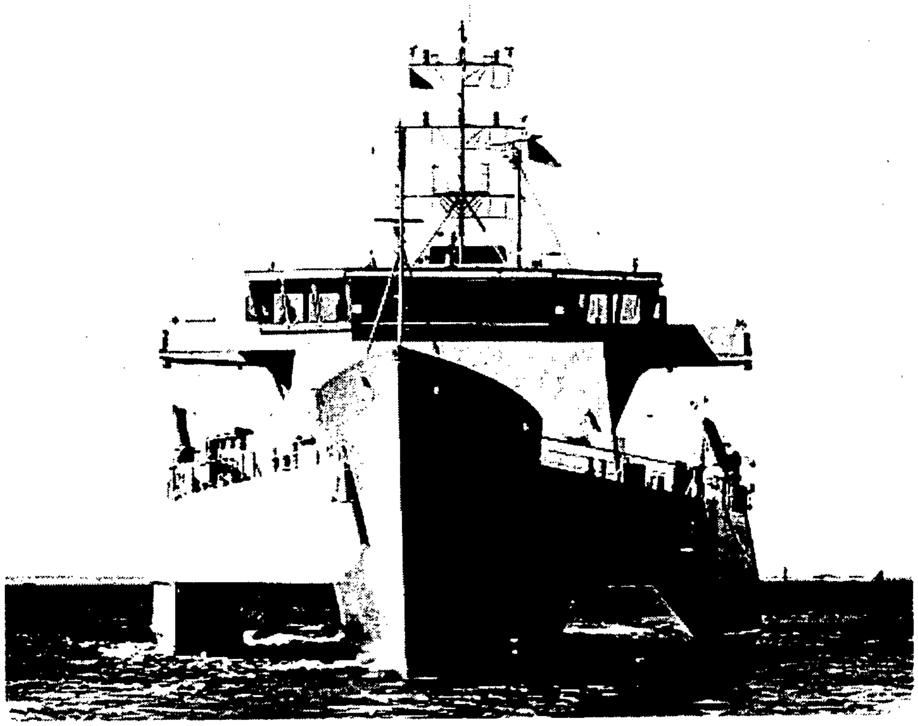
The remaining two hull forms to consider were the Mono-hull design and the Multi hull design. The benefits of the monohull design are obvious: It represents what has always been done. Nearly all cargo ships, or any class of ship for that matter,

are monohulls. Over the years, the monohull design has been improved and refined, and so there are years of experience to fall back on. There is a massive amount of data known about the performance of this hull form, everything from their hull resistance to their stability had been thoroughly researched and documented. Computer programs are also available that can predict monohull performance based on certain ship design parameters. In addition, the entire ship construction and repair industry is geared towards building and servicing monohulls. Most channels, bridges, drydocks, canals and ports are configured for accepting monohulls. Thus, a monohull design ensures that existing facilities could be used for support. So clearly a monohull design would meet the needs of the Sea Force Ship.

The final hull form for us to consider was the multi-hull design. Many research papers were found that investigated the benefits of large multi-hull configurations for future cargo ships. Most of this research involved tri-hull designs, leading to a focus primarily on the tri-hull concept for the Sea Force ship. There are also several large trimaran designs being investigated, again for future container ships, which can claim both good speed and high hull efficiency.

Tri-hull designs have many characteristics that would be advantageous to a ship such as ours. The small outrigger hulls associated with the traditional tri-hull design make the ship much wider giving the potential for a much larger flight deck, open cargo areas and enhanced stability. The hull form is efficient, allowing it to travel at relatively high speeds without extremely large power requirements. Tri-hulled ships usually have a large center hull, with two smaller outriggers, which makes their configuration similar in nature to existing

monohull ship designs. The center hull can be wide enough to incorporate a well deck. In 2000, the HMS TRITON was constructed, the largest tri-hulled ship ever built, see picture below.



With a displacement of approximately 2000 LT, it has undergone testing in the British Navy, and has demonstrated many of the benefits that a tri-hull design has to offer. However, The Sea Force Ship was predicted to be more than 20 times as large, introducing many more complications in design and operation.

In the end, after comparing the two options, a tri-hull design was chosen. This decision was driven largely by the increase in flight deck requirements due to Ship To Objective

Maneuver (STOM), as well as the potential to use the area between hulls as a staging area for LCU operations.

2. Hull Design

When deciding to go with a tri-hull configuration, several assumptions were made. Applying the tri hull form to a large cargo ship application is a fairly new concept, and not a lot of research exists regarding this type of vessel. Thus, some aspects of the design proved to be difficult to predict, given the time given for completion of this project. In addition, it was recognized that no large tri-hulled vessel has ever been built, so ship construction techniques for this type of vessel are not proven. At the very least, there are not very many, if any, drydocks that are wide enough to handle a vessel of this size. There were also concerns about the size of the ship, and how it would affect port access and stresses in the structure of the ship while at sea. These topics will be discussed later.

Before designing the hulls, some limits were placed on their maximum dimensions. The anticipated payload for this ship was extremely large, and this let to the concern that the ship would grow unrealistically large. For this reason, and to ensure port accessibility, it was decided that the ship would not be more than 1000 feet long, shorter than the largest aircraft carrier. The draft was held to 43 feet or less for the same reason, so that it would not draft more than a fully loaded aircraft carrier. The goal of these restrictions was twofold: the ship had to be able to fit into existing ports, and it had to be of a reasonable size for construction and maintenance purposes.

After this was done, hull design began. The center hull was designed first, using the TAK-R ship hull as a baseline hull form. The TAKR is an approximately 30,000 LT RO/RO ship used by the United States Army to transport military equipment. This hull data was obtained from NSWC Carderock, by Professor Papoulias. The data was entered into RHINO, a rendering computer program, so that it could be viewed. This hull form was then modified to better suit a tri-hull application. Research on Tri-hull ships indicated that the hulls for these ships have a much higher length-to-beam ratio than traditional monohulls, to reduce the wavemaking resistance associated with each hull. So the length-to-beam ratio of the TAK-R hull was increased by stretching it from 700 feet to 990 feet, just short of the maximum length of 1000 feet. Hull width was narrowed to 106 feet, and draft was increased to 43 feet, again not exceeding the 43 foot draft limit that had been set. Both the stretching and thinning were done proportionally, so that the lines of the hull remained smooth. These changes gave the center hull a length to width ratio of 9.3. This length to width ratio is high for a cargo ship, leading to a reduction of predicted wavemaking resistance. However, this ratio is at the low end of the spectrum for the center hull of trimaran designs. There are also smaller surface combatants that have a higher length to width ratio, but their mission is much different. These dimensions led to a displacement of just more than 70,000 LT, which met the requirements of the initial analysis of alternatives.

Upon inspection in the Rhino modeling software, it was clear that another change had to be made to the hull. The stern had a rounded section profile, and came to a point, which left no place for a well deck. To accommodate a well deck, the stern

was significantly changed. First, the stern section was made much more boxy, using a quadratic manipulation of the hull offsets. This gave a very smooth transition between the original mid-ship coefficient and the new stern. The stern was also kept wide, and a gradual decrease in draft at the end was added to facilitate the placement of propulsion devices. The gradual decrease in draft was modeled after the LHD stern, and this provided the ship with a transom, and space for the propulsion pods that were eventually chosen to propel the Sea Force Ship. Because of the shape of the stern, the propulsion pods will not extend below the bottom of the ship, so they are protected, i.e. the hull will ground out before the pods hit anything. Pictures of the main hull can be found in the report presentation, and are not included here for brevity.

3. Outrigger Hull Design

The outriggers served several different purposes in this design. First, they provided buoyancy and stability, due to their location outboard of the center hull. They also served as a protective outer barrier to the center hull. These two purposes conflict, it is not desirable to have an area of the ship designed to take hits if it is an important source of buoyancy. So the design of these outriggers was important, and this was kept in mind during the design process.

The outrigger hulls were sized using relations found in the literature. The relation for outrigger displacement is:

$$\frac{2\nabla^{outriggers}}{\nabla^{T}} = 0.14$$

With an 87,500 LT vessel, this gives each outrigger a displacement of 6125 LT. The final design of the outriggers

gave a displacement of 6000 LT each. The relation for outrigger length was taken from the same study, is:

$$\frac{length^{outrigger}_{waterline}}{length^{mainhull}_{waterline}} = 0.46$$

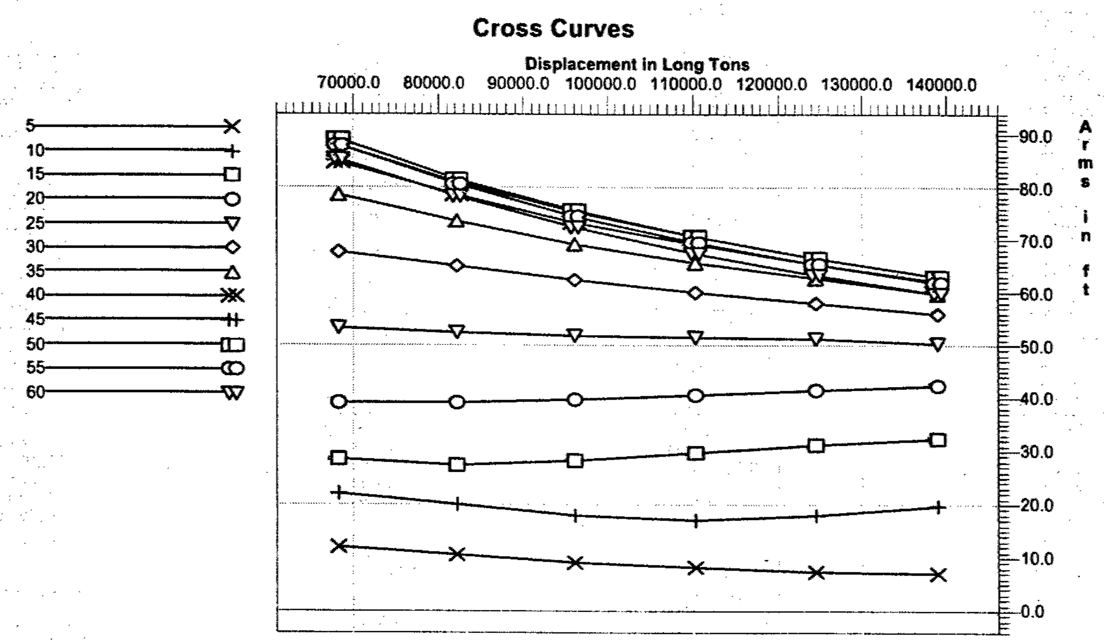
According to this relation, with a ship length of 990 feet, the outrigger hulls would be 460 feet long. This length was extended to 550 feet, to allow for a decrease in outrigger hull width. This improves outrigger hull efficiency, because the length-to-beam ration is very large, 25, indicating a smaller wave making resistance associated with each of these hulls. This increase in length was also done to increase the length along which the center hull is protected by the side hull. Pictures of the outrigger hull can be found in the report presentation, and are not included here for brevity.

The outrigger hulls were placed amidships along the center hull. This was done to comply with a study that said amidships was the best place for outriggers on a large medium-speed tri-hull vessel. Width of the ship was determined by the required flight deck space. To allow for triple tram lines of MV-22s, a flight deck width of 300 feet was chosen. This helped to determine the placement of the side hulls. The outriggers were placed 140 feet off center. Because the center hull is 106 feet wide, and the outriggers are 20 feet wide, there is a 77 foot space between the hulls. This space was wide enough to easily fit an LCU, and so this space was designated as an LCU staging ground, where LCUs could pull in and onload/offload equipment. The specifics of this evolution are covered in more detail in the internal arrangements section of this report.

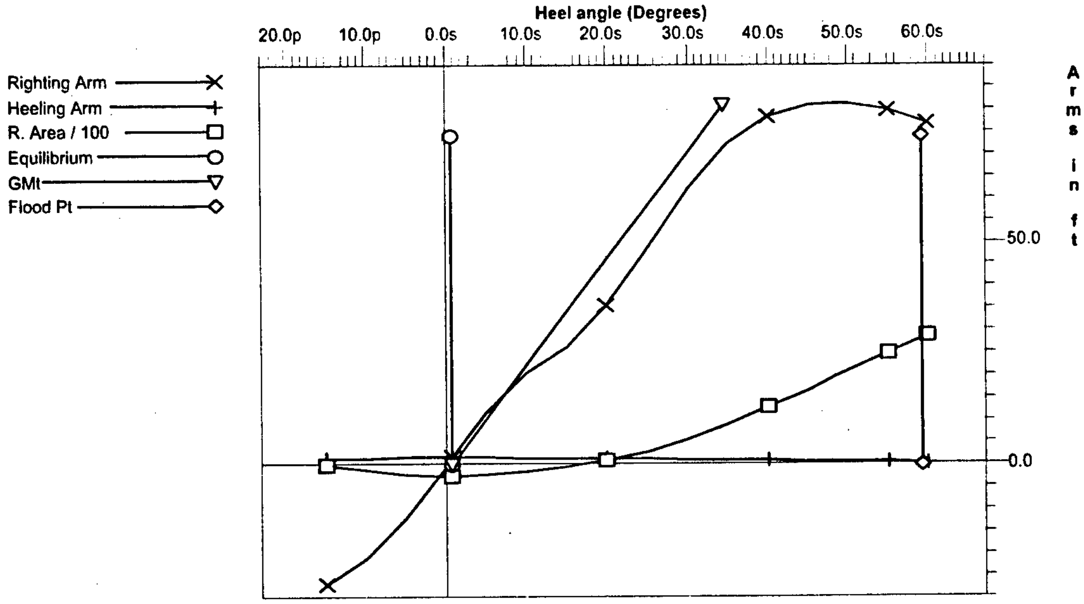
A wave piercing bow was used in all three hulls, for two reasons. First, it was an innovative design, and has been seen on recent future naval combatants, so it was also used on our design. Also, the wave piercing bow reduces the pitching that is encountered in a traditional flared bow, while in heavier seas. A bulbous bow was also included in the design, to reduce wavemaking resistance when the ship is at transit speed, to increase the efficiency of the hull. Pictures of the complete hull can be found in the report presentation, and are not included here for brevity.

4. Stability

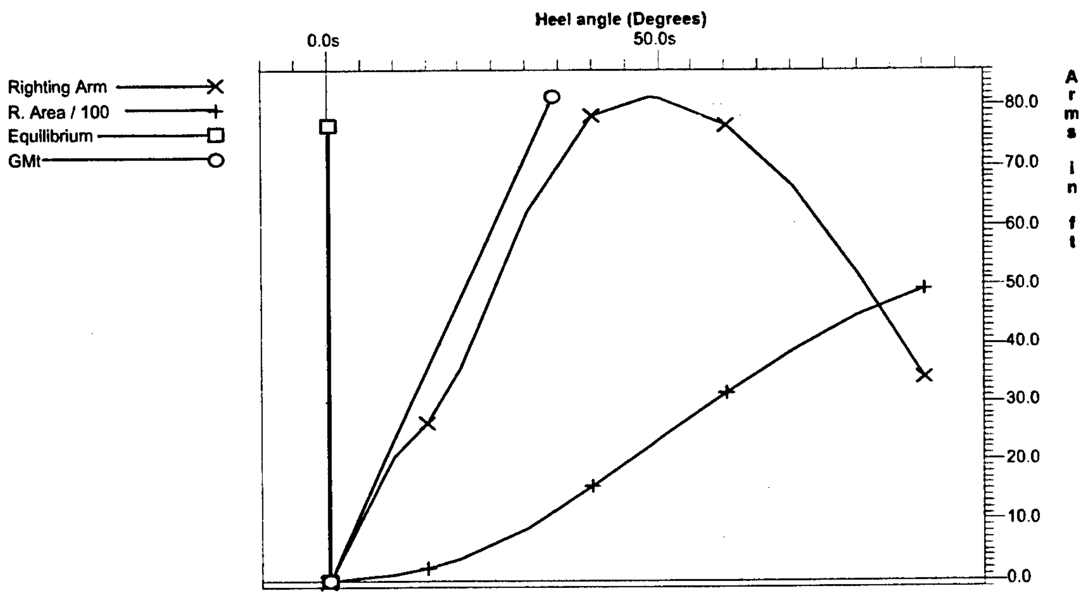
Stability calculations were done with the computer program AUTOHYDRO. Once the hull had been designed in RHINO, the data was imported into AUTOHYDRO, and stability analysis could be performed. The following graphs sum up the results that were found.



Righting Arms vs. Heel



Righting Arms vs. Heel



The data in these charts is part of the report given by AUTOHYDRO for the Sea Force Ship. Parts of the report are attachments to this project.

5. Structural Concerns

Because of the nature of a Tri-hulled ship, high stresses were expected in parts of the design, especially around the structure that connects the three hulls. This is because in waves, the three hulls of a tri-hull design will react independently to the sea state. Thus, high stresses are expected in the octagonal superstructure that connects the three hulls. For stiffening, a very robust structure in this octagonal superstructure was used. 4 foot of height across the entire octagon was dedicated solely for structure above the 0-4 level, and another 3 feet was allocated below the main deck. This is in addition to normal stiffeners and other structural members that are associated with ship structure. Aircraft carriers incorporate structure into the first deck under the flight deck, and this can also be done for different decks in the Sea Force Ship as well.

Another anticipated source of structural stress comes from ballasting. This ship is carrying a large number of troops, equipment and supplies, and in some cases it will all be taken ashore. The cargo adds up to more than 10,000 tons, and there is the potential for all of this cargo to go ashore. This means that 10,000 tons of ballast would needed to keep the well deck at the waterline. To do this, the ship has to have an additional 10,000 tons of ballast tankage built into the design. The placement of this much ballast will have a great impact on the stresses encountered in the ship's structure, especially in the ballasted condition.

To calculate longitudinal bending, a detailed weight analysis was completed. This weight distribution was entered into AUTOHYDRO, and a maximum longitudinal bending moment was found. This stress was found to be 6,870,100,000 ft-tons, just forward of amidships when the ship is in light ship condition. The following figure is the longitudinal strength graph for the full load condition.

To determine how much structure was needed to counter this bending moment, the midship section at this point in the ship was analyzed. The outer hulls and decks were all assumed to be 0.5 inches thick, and the midship section coefficient was calculated. When converted to psi, the stress predicted by AUTOHYDRO was 10,050.0 psi. Standard allowable stress level is 15,000 psi, and so with just the existing structure, there is a 1.5 safety factor in the predicted stress levels for the worst loaded condition. All of these stresses are for a static condition, and a dynamic analysis must be done to determine the levels of stress that would be encountered in seakeeping conditions.

The calculation of the midship section coefficient was very conservative, most of the hull plating and deck plating for a ship of this size is generally thicker than 0.5 inches. In addition, there will be many other structural members, stiffeners and columns and such, that will greatly increase the value of the midship -section coefficient, driving up the safety factor for longitudinal stress.

Transverse stress is another type of stress that can be large in tri-hulled vehicles. This type of stress was not calculated, although because of the small displacement of

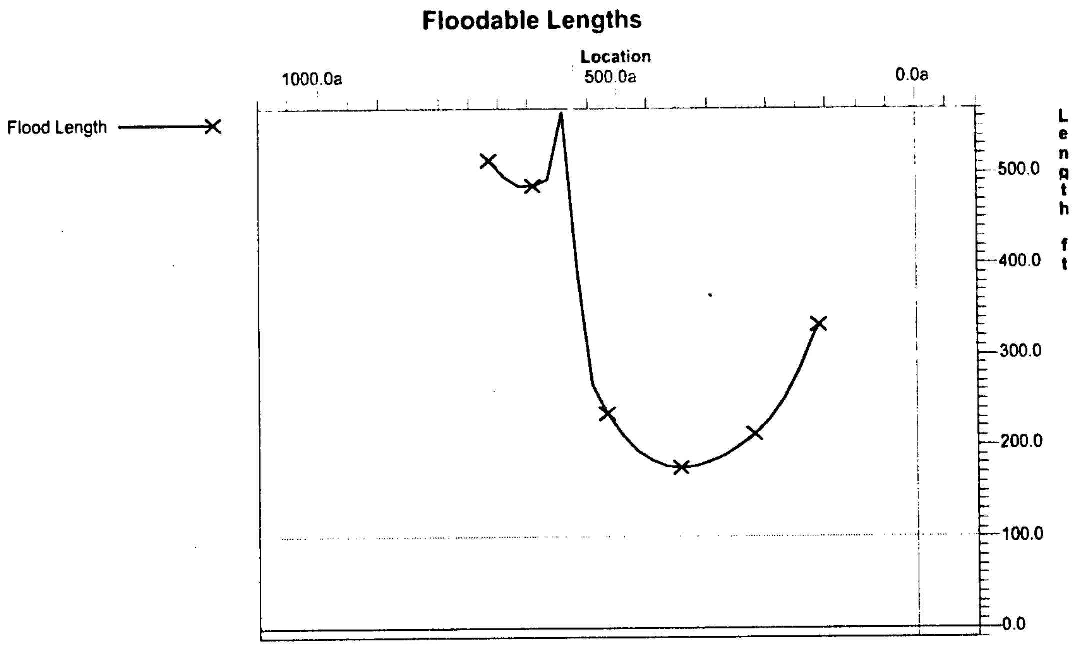
outrigger hulls in relation to the center hull, this stress will be less than that associated with a catamaran-type ship. For a more in-depth analysis of hull feasibility, this should be analyzed

Flight deck thickness, taking into account the imbedded systems in the deck (including electric, fuel, pneumatic and water connections) was predicted to be one foot. On top of the 4 foot thick upper structural area, this deck will be able to support the heaviest of air vehicles that will operate from the flight deck.

Overall, 40,000 LT of the ship (nearly half of the total displacement) was predicted to be structure. This should be more than enough to satisfy the heavy structural requirements for this ship, due to the increased stresses associated with the trimaran hull form. However, heavier structure also makes the ship more durable to attack, giving more mass to absorb damage, if the structure is properly and effectively distributed about the ship.

6. Floodable Length

Navy standards for floodable length dictate 15 % of the ship should be able to flood without submerging the margin line. This problem is made This standard does not apply to current US Navy amphibious warfare ships such as the LHD and LHS, whose long, open vehicle decks make it impossible to achieve the 15% flooding limit. Because of the tri-hull design, our ship is able to meet this standard. It is assumed that for flooding purposes, the well deck is assumed to be open to the sea at all times. The margin line was chosen to be 73 feet above the keel.



Flooding of the side hulls is also critical, because they are located far from the center of the ship, and will have a significant impact on the list of the ship. Quick calculations indicate that even with significant flooding, the ship will only list a few degrees, which should allow flight deck operations to continue. In addition, a list can be countered by using some of the many ballast tanks, several of which are located in the outrigger hulls.

7. Conclusions

More analysis needs to be done on tri-hull forms. There are many unknowns about this hull type that need to be researched. New books are being written about multi-hull ship performance, and more studies are being done to determine the feasibility of large ships with a tri-hull configuration. But still, there are a great number of unknown performance-related parameters regarding the performance of a large tri-hull ship.

A more detailed analysis of structure is needed for a ship such as this. After a specific structural layout is created for each deck, a much better idea of the needed structural weight of the ship will then be available, which will help to better complete the other aspects of the design of this ship.

Finally, another trip around the design spiral would allow for significant refinement of the ship design, from stress calculations to weight distribution to hull dimensions. However, the design reflects the general look that this ship would have, and that is enough to determine that this ship design is both feasible and practical for use by the Navy. With a ship of this design, the major changes in amphibious warfare such as STOM and selective offload can be realized, and the capabilities of the United States Navy and the United States Marine Corps will be greatly enhanced.

B. FLIGHT DECK LAYOUT

Ship to Objective Maneuver (STOM) operations are heavily demanding on air assets. Future expeditionary operations will require the deployment of the entire Ground Combat Element (GCE) in a limited time to ranges up to 200 NM. Furthermore, once the initial assault has been executed, the forces will require reliable and precise delivery of supplies. Support to the troops ashore will include casualty evacuation, both human and equipment. Logistical support will be performed by MV-22s and AERO design Heavy Lift Aircraft. In addition, JSFs will constantly fly Close Air Support (CAS) and escort missions in support of the forces ashore and Combat Air Patrol (CAP) mission to protect the assets of the Sea Base. The result of this high

tempo on aviation assets was a driving factor for the design of the flight deck and ultimately for the hull and the entire ship.

1. Aircraft

Requirement calculations for the air wing during the assault and sustainment phases resulted in a complement of 16 MV-22, and four Aero Heavy Lift Aircraft design. In addition, the air wing will also include four UH-1Y Command and Control helicopters, four AH-1Z Super Cobra attack helicopters, four SH-60F USW and SAR helicopters, and two Unmanned Aerial Vehicles (UAV). For further information about each type of aircraft as well as the air operations, flight deck management operation concepts refer to section VI-H-2.

Air Elements	Per ship
Aero Heavy Lift Aircraft	4
MV-22	16
AH-1Z	4
UH-1Y	4
SH-60F	4
STOVL JSF	6
UAV	2

Table 15. Air Wing Requirements for Sea Force

2. Dimensions

The flight deck is octagonal in shape, dual tramline, which allows both rotary and STOVL aircraft concurrent operations. The corners of the flight deck are cut at a 45^0 angle from the perpendicular 102 ft from the forward and aft flight deck edges. The flight deck extends for 770 ft, and has a width of 300 ft for a total area of $231{,}000ft^2$.

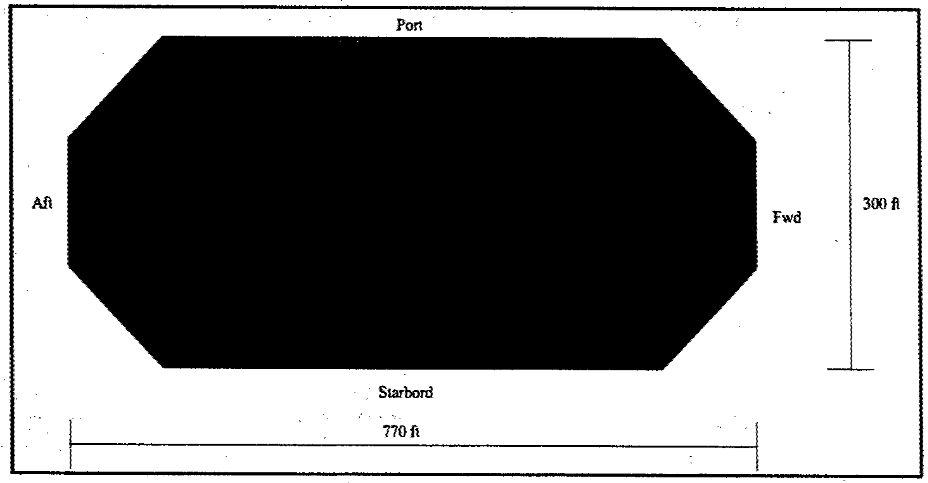


Figure 32. Flight Deck Dimensions

3. Aircraft Spots and Runway

There are a total of 16 aircraft spots. There are five aircraft spot labeled 1B through 5B on the port side. Six aircraft spots labeled 1 through 6 are position centerline, and five spots labeled 1A through 5A on the starboard side. All aircraft spots are 115 ft apart with the exception of spot 6, which is at a distance of 85 ft from spot 6. The length was calculated from the LHD-1 NATPOS Manual [34], which states that there must be a clearance of at least 15 ft between aircraft rotors. Taking the length of the CH-53E as the unit, its 100 ft length was added to the 15 ft requirement.

All 16 spots can be occupied by MV-22. CH-53s can occupied all of the aircraft spots with the exception of spot 6, which does not comply with the rotor clearance requirement. The Aero Heavy Lift aircraft occupies two aircraft spots.

The runway for the fixed wing STOVL aircraft is 770 ft long, and 100 ft wide from foul-deck to foul-deck lines. The take off requirement for Joint Strike Fighter loaded with 2 x

1000 JDAM and 2 AIM 120 is 550 ft [35]. Figure illustrates the flight deck arrangement.

4. Flight Deck Monitoring System

Radio Frequency Identification (RFID) transponders/readers with various available inlay shapes, form the basis of the flight deck sensor grid. Multiple HF transponders, which appear in the readers RF field, can be written to and read from by using a programmable Simultaneous Identification (SID) number. The reader works at High Frequency (HF). The system comprises a reader, antenna, and transponders. The reader module handles all RF and digital functions in order to detect several transponder frequencies [37].

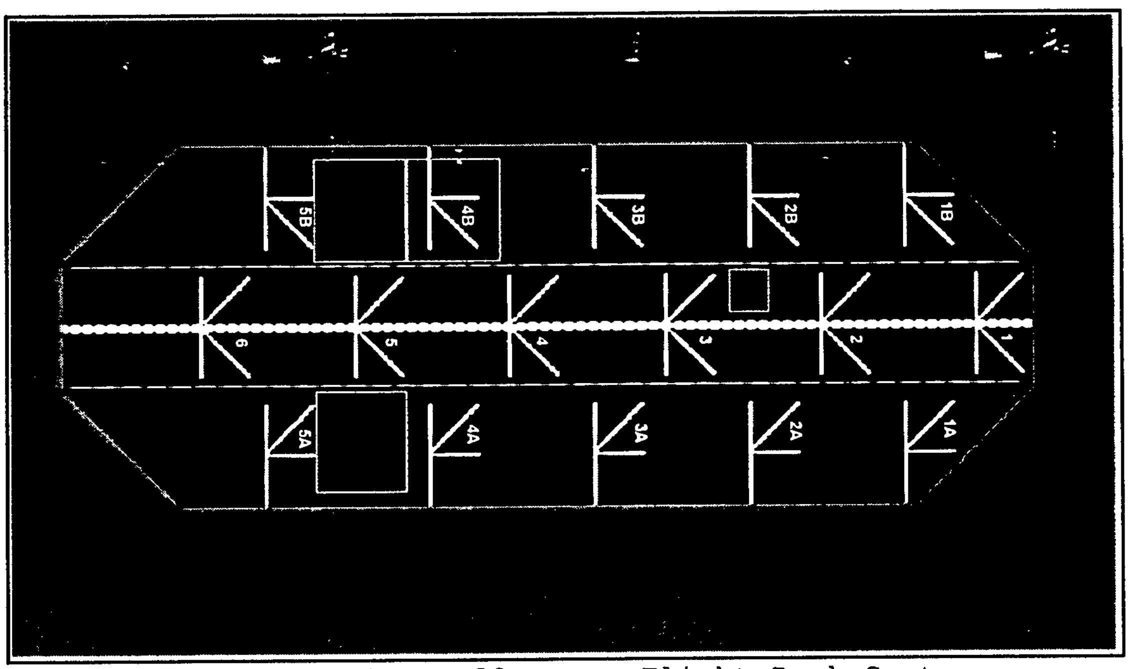


Figure 33. Flight Deck Spots

Air Elements	Per Ship	Spot Factor Spread	Total Flight Deck	Spot Factor Folded	Total Hangar Bay

			Area		Area
Aero Design	4	10,530	42,120	5,400	21,600
AH-1Z	4	2,477	9,908	573	2,291
UH-1Y	4	2,477	9,908	642	2,567
SH-60 F	4	2,477	9,908	642	2,567
MV-22	16	5,085	81,365	1,532	24,509
STOVL JSF	6	1,056	6,334	1,056	6,334
UAV	2	110	220	110	220

Table 16. Aircraft Spot Factors, Flight Deck, and Hangar Bay Area.

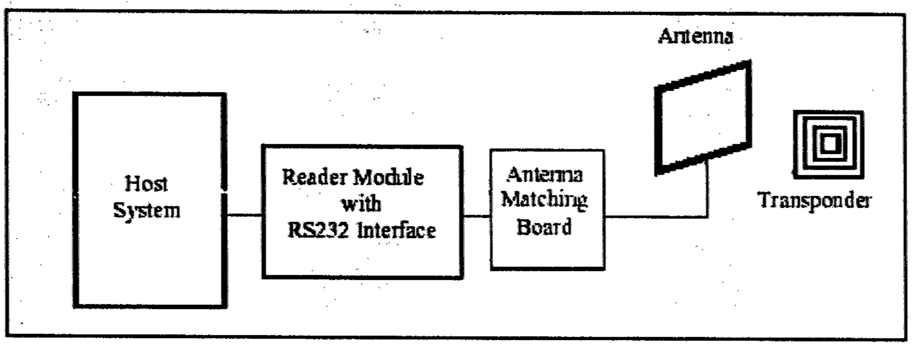


Figure 34. Block Diagram of Flight Deck Identification and Monitoring System (Source: Texas Instruments)

The flight deck will have a total of 525 antennas spread in a square pattern. The separation between antennas is approximately 20 ft. Figure 35 illustrates the position and distribution of the antennas. Every aircraft, piece of equipment, and personnel will have a transponder that will uniquely identify it and relate its position to flight deck control. Management of flight deck operations will be automatically recorded and updated in an electronic log. Since every transponder can be uniquely identified and data recorded

on it every aircraft or equipment status (mission information, repair status) can be tracked electronically. This information will be visually correlated by a network of television cameras that will be located in every aircraft spot and on the perimeter of the flight deck. For detail information about the flight deck sensor grid, refer to section IV-D-2 flight deck technology enablers.

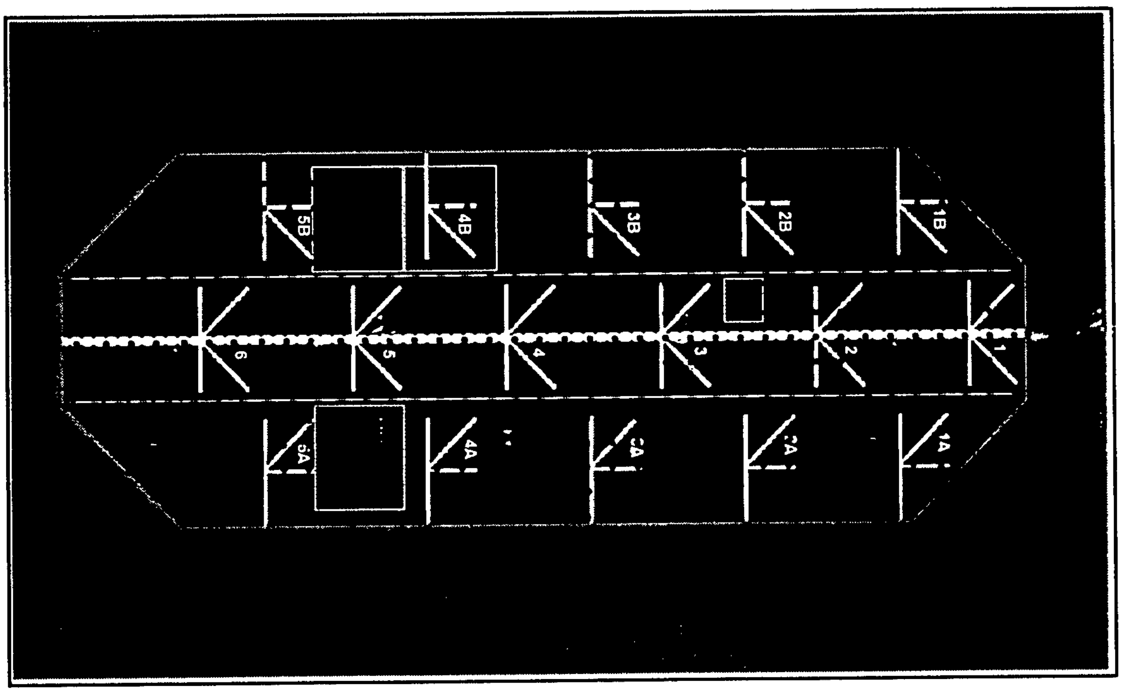


Figure 35. Flight Deck Antenna Grid

5. Spot Signal Beacons

Each of the 16 aircraft spots on the flight deck will have a deployable navigation and signal beacon that will act as an Landing Signal Enlisted/Director (LSE). When not in use, the beacons will re-tracked and stored flushed to the deck. When an

aircraft has been instructed to land or launch, the designated spot beacon will extend from the deck. For long range navigation, every beacon will transmit a HF navigation signal that will indicate the pilot his position relative to the beacon. Once on final, the pilot will approach the deck using the traditional visual aids [34] described on Figure 36.

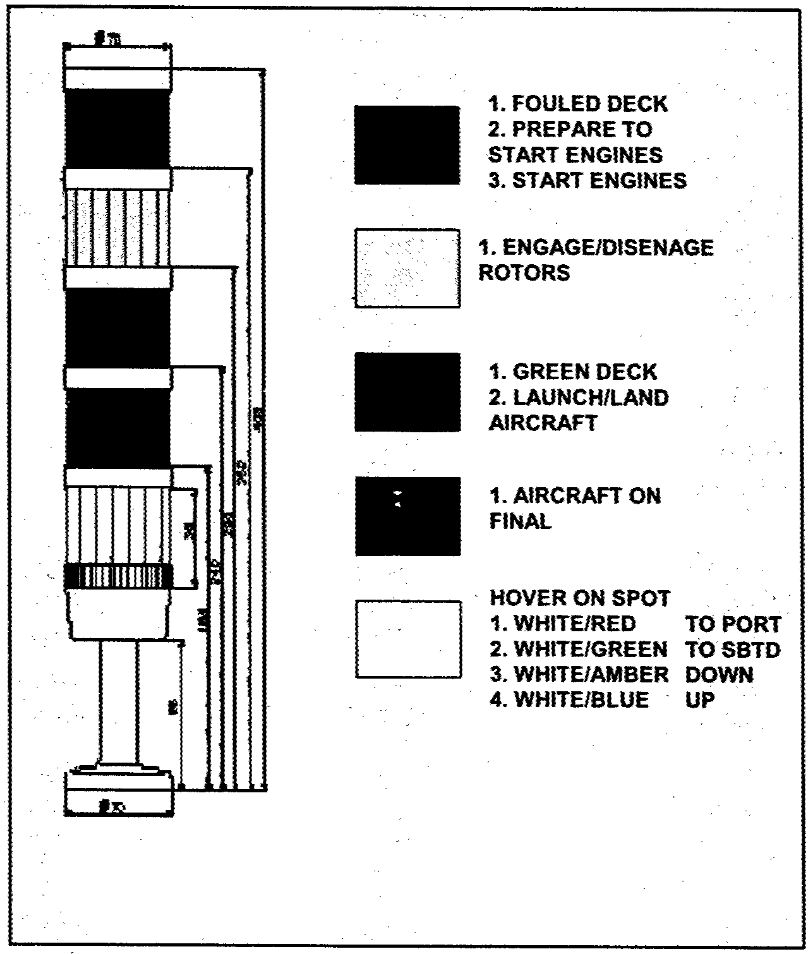


Figure 36. 36 Flight Deck Spot Beacon

6. Aircraft Elevators

There are three hydraulic, deck edge type, flight deck elevators. All three elevators run from the flight deck, to the hangar bay deck. Each elevator is 70 x 70 ft, and has an area of 4,900 ft ^{2}. Aircraft Elevator 1 is located on the starboard side 705 ft from the forward flight deck edge. Aircraft Elevators 2 and 3 are side by side. Elevator 2 is the most forward, and is located 405 ft from the forward flight deck edge. All elevators have a rated capacity of 70,000 lbs.

Elevators 2 and 3 are compound; they can operate independently or simultaneously to lift or lower the Aero Heavy Lift Aircraft. Number 1 Aircraft Elevator Machinery Room is located in the starboard side hull, and occupies a volume of 22,400 ft^3. Number 2 and 3 Aircraft Elevator Machinery Rooms are located in the port side hull and occupy a volume of 50,400 ft^3.

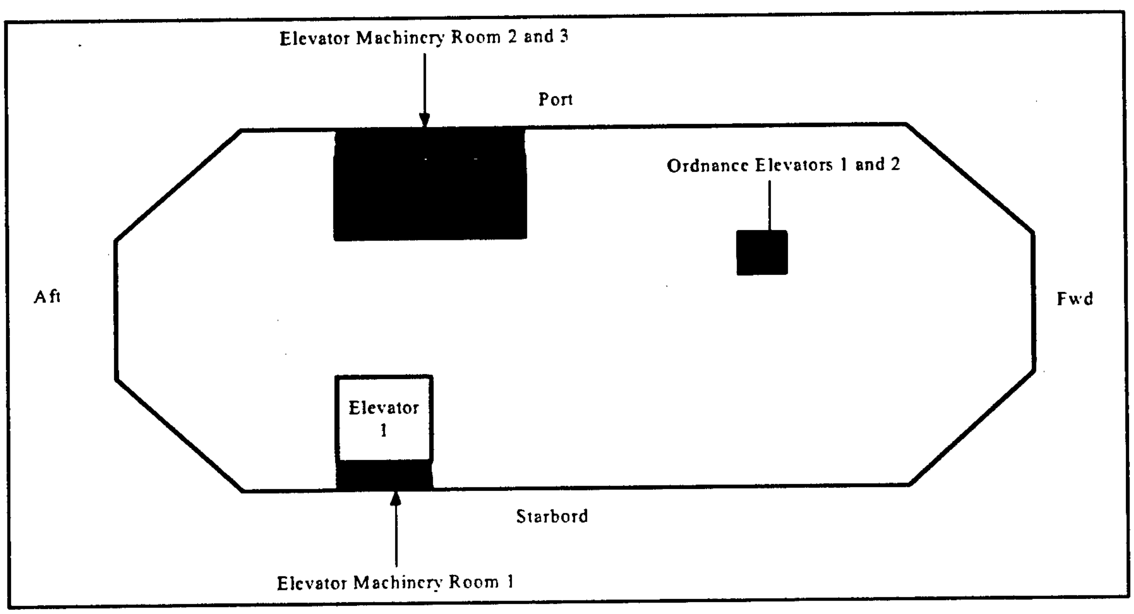


Figure 37. Flight Deck and Ordnance Elevators

7. Ordnance Elevators

There are two ordnance elevators that service the 3th and 4th deck magazines. Each elevator has a length of 30 ft and a width of 15 ft, covering an area of 450 ft^2. Figure 37 shows the position and size of the ordnance elevators with respect to the aircraft elevators. Ordnance elevator 1 is position 200 ft from the forward flight deck edge. Both elevators are 10 ft off center from the centerline. The elevators shaft runs from magazine 1 and 2 on the 4th deck to the flight deck, and services magazines 3 and 4 on the 3th deck, 2 nd and 1st vehicle decks, hangar bay and warehouse on the main deck, and the flight deck. The elevators rated capacity is 25,000 lbs. With this cargo capacity the elevators will have the capacity to lower or retrieve 10 ammunition pallets each pallet weighing approximately 2,400 lbs. The primary technology for this type of ordnance elevator is a spindle screw actuator with condition-based maintenance built in. The system includes a new, faster ballistic hatch and a highly dexterous mobile elevator carriage. This new weapons elevator and ballistic elevator shaft cargo hatch for aircraft carrier-type weapons elevators will improve weapons handling rates with reduced maintenance and enhanced utilization flexibility [36].

C. INTERNAL VOLUME LAYOUT

The design team goals for the internal layout were to ensure as much system redundancy as possible, eliminate the need for machinery in as many cases as possible, and to avoid the creation of systems with a single-point-of-failure. Other important factors considered for space allocation during this

design stage included weight distribution, system requirements and priorities, component size, damage control and containment, and collective CBR protection.

The layout of the internal volume was determined through an iterative process in which the major areas of the ship that had little flexibility in location were designated first. This was followed by the incorporation of the smaller spaces with more flexibility in location. In considering the layout, it was also important to maintain a similar layout to that of warships, collocating ship's Commanding Officer berthing with the major decision making areas on the ship (CIC, the Bridge and Joint Staff spaces for example). Additionally, it was important to keep ammunition spaces well protected. Due to the fact that the movement of cargo, ammunition and aircraft was a driving factor in the overall design, ample areas were needed through which this movement could occur. The final layout above the waterline combined four decks forward of the warehouse area consisting of combat systems and berthing spaces with three decks aft of the hangar bay consisting of vehicle/cargo storage, medical, AIMD, MER3, and berthing. This layout can be seen in Figure 38 below:

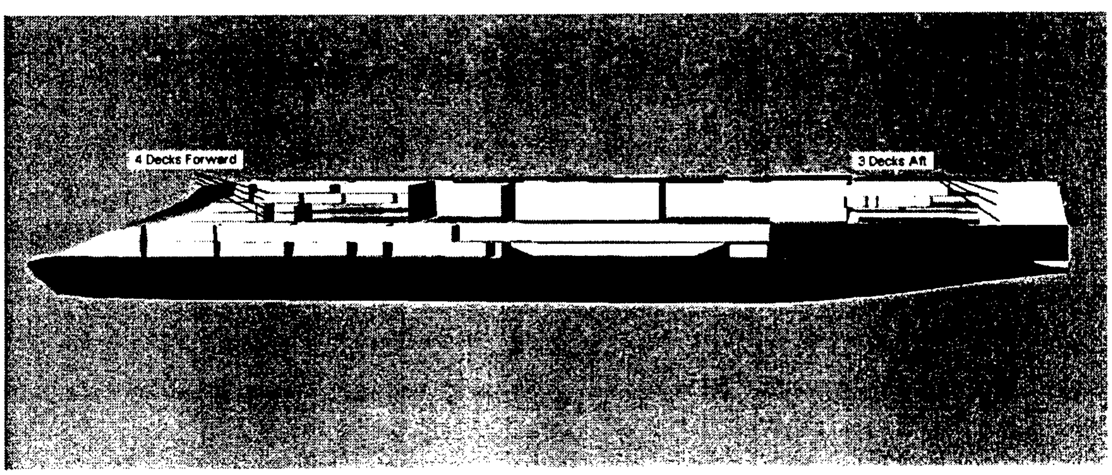


Figure 38. Side View of Internal Layout

1. Well Deck

The three most significant areas that drove the ship's internal layout were the well deck, the hangar bay and the vehicle/pallet/cargo storage areas. The well deck was placed at the waterline (approximately 40 feet above the keel) to allow for LCAC operations. Based on transfer requirements, 4 LCACs were needed to support STOM. The first iteration of the internal layout for Sea Force allowed for 4 LCACs stored two deep and two across as seen in the diagram below:

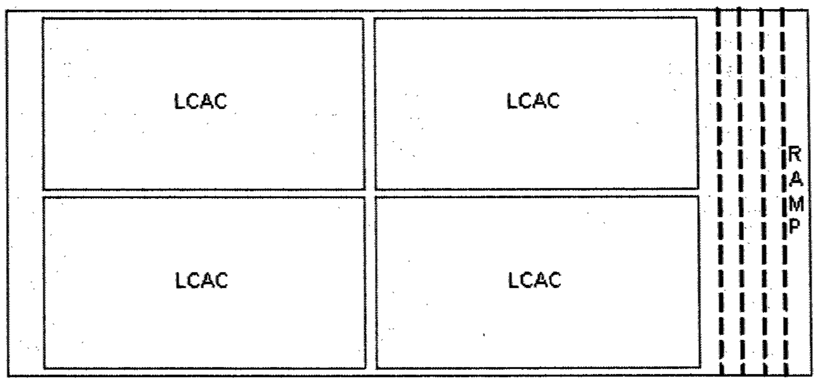


Figure 39. Initial LCAC Layout

However, upon subsequent findings, it was determined that the beam of the main hull was not of sufficient width to accommodate two LCACs side by side. An LCAC must enter the well deck on cushion. The original well deck design was just as wide as two LCACs side by side and did not permit room for two to come in on cushion in this arrangement. The HLCAC, however, became a possible solution [39]. The proposed craft would increase in both length and cargo area by thirty-three percent over the present LCAC and would have double the payload (144 tons vice ~70 tons). The HLCAC would be capable of carrying two M1A1 tanks or 10 light armored vehicles (LAV). Although the HLCAC is still a conceptual program, it would be more feasible to

design the HLCAC around a given well deck size (as was done for the original LCAC) than to design a ship that is not capable of carrying the required number of LCACs. Given that a present day LCAC is 88 feet long on cushion, the HLCAC would be approximately 118 feet long on cushion. Thus, the well deck was designed at 250 feet to accommodate for a stern gate and 60 feet wide to ensure the HLCAC could drive in easily on cushion without danger of puncturing the cushion. To accommodate for AAAV launching and recovery, a stern ramp was built into the well deck at the aft end. This ramp is below the design waterline so that the AAAVs can drive directly into or out of it. At the forward end, a ramp leading fifteen feet up to a 40 foot long by 260 foot wide staging area was incorporated to allow for loading and unloading the LCACs. The staging platform will be used to arrange vehicles and to group vehicles prior to loading onto LCACs. Finally, the well deck was sized to contain a high-pressure water spray decontamination system at the entrance, to facilitate decontamination of LCACs as they enter from a contaminated environment. The overall schematic of the well deck can be seen in Figure 40 below.

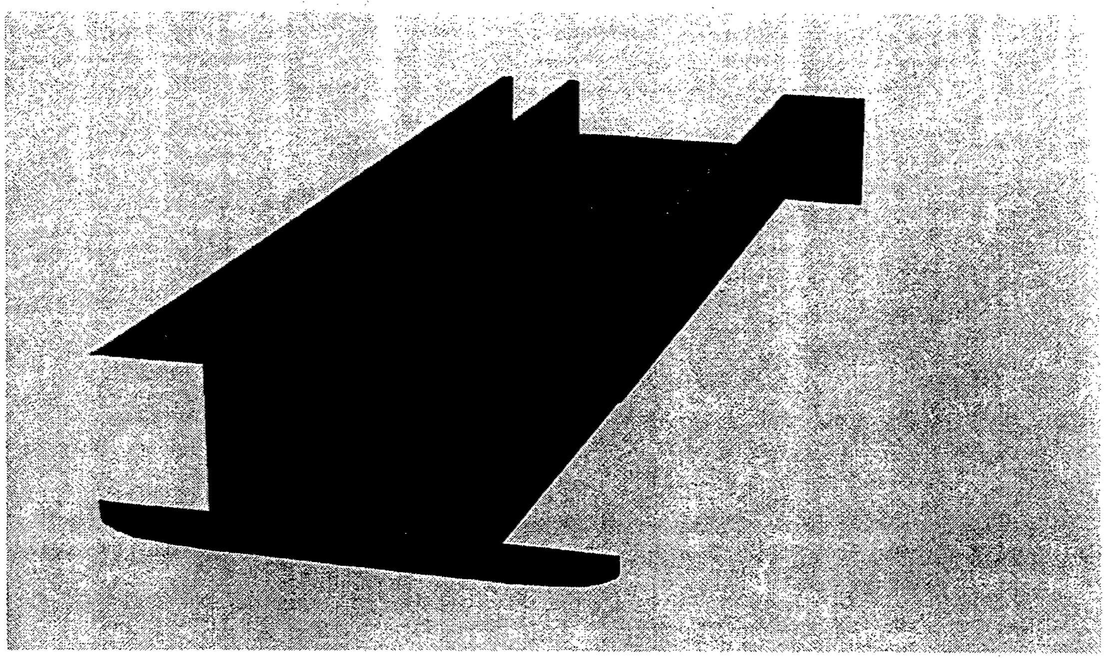


Figure 40. Well Deck

2. Hangar Bay

The second major area of consideration in the internal layout was the hangar bay. In order to maximize the dimensions and layout of the hangar, it was initially designed to span the entire beam of the ship. The aircraft elevators were a driving factor in the overall placement of the hangar bay. Three aircraft elevators are used to give access to the flight deck from both sides of the hangar, two on the port side and one on the starboard side. To maximize the hangar day area, the elevators were placed at the extreme beam where the side hulls went completely from the flight deck to the keel of each. Due to the fact that this portion of each side hull was located approximately 205 feet forward of the stern, the elevators could not be placed aft of this in order to ensure that there was ample room for the required elevator machinery. Two of the elevators on the ports side can be connected to create one compound elevator with the combined lifting capacity of both

elevators. This is the only way to transfer the heavy lift aircraft from the hangar to the flight deck. Because the aircraft elevators were planned to be used for transfer of light vehicles, containers, equipment and potentially ordinance to the flight deck, the hangar deck was designed with lanes for throughput of these items. No consideration was made for an aft elevator due to the fact that the stern elevator gets little use on the LHD class ships and that the AIMD and MER3 spaces require intake or exhaust outside the skin of the ship, both of which could be accomplished by placing them at the stern. Given the above-mentioned elevator constraints, the hangar bay could start no more than 205 feet forward of the stern if the elevators were to be at the aft end.

In order to fit all of the aircraft in a folded configuration, the hangar bay had to be approximately 70,715 square feet. With a 300 foot beam, this required approximately 240 feet of hangar bay. After several iterations, the external bulkhead around the superstructure was designed at and angle of 13°, cutting of some of the volume of the original hangar bay. The design was than altered to make the hangar bay 260 feet wide. Additionally, the LCUs required storage areas above the LCU decks (into the hangar bay) in between the main and side hulls, taking approximately 6,400 square feet each for a total of 12,800 square feet. Finally, the motion compensated crane was to be placed on the starboard beam of the ship at the O-3 level. This took additional space from the hangar bay. In order to compensate for all of these losses, the hangar bay grew from 240 feet to 320 feet in length with a 36 foot height. Hangar deck height was based on the highest unfolded aircraft, which was the CH-53. Unfolded, the aircraft is 29 ft tall. The ultimate height of the JSF may be 30 feet tall and thus become

the driving factor for hangar bay height. To allow space for maintenance above the tallest aircraft and to allow for a crane to be placed in the overhead (to remove heavy objects such as rotor blades and engines), the hangar was initially sized to a height of 35 feet. After changes were made to the forward decks, the final height became 36 feet. A rough schematic can be seen in Figure 41 below:

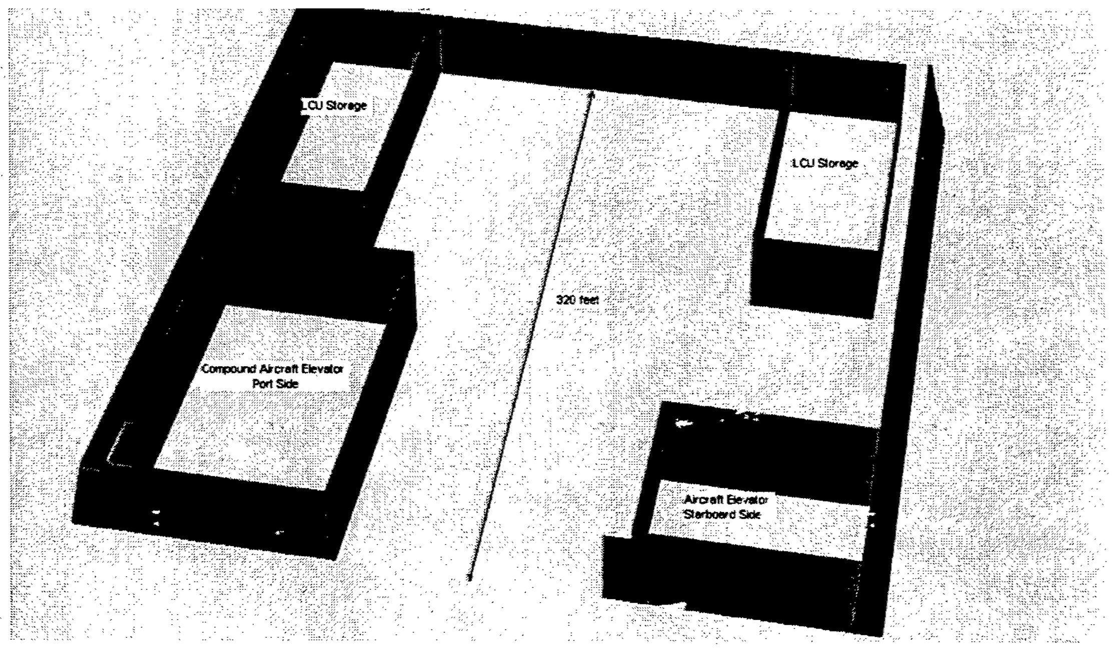


Figure 41. Hangar Bay

3. Vehicle Decks

Vehicle deck layout was the third major area of consideration and a critical factor in the success of selective offload. Mechanical vehicle storage systems, such as moving decks, that give access to each vehicle were considered for the selective offload process, but were not used because of the single-point-of-failure associated with them. Additionally, fewer mechanical systems meant less required maintenance and

less manning. The final design incorporated traffic lanes for selective offload, with each vehicle able to drive into a traffic lane for subsequent navigation to its point of exit. The need for traffic lanes and "parking spaces" drove the space requirement for these decks. Four vehicle decks were decided upon, with ramp access between each of them. Each vehicle deck was given two points of entry/exit so that if one was blocked, vehicle movement could continue. In addition, all decks have access to the well deck, forward vehicle offloading points and hangar deck. The length of the decks was a consideration since floodable lengths are important to the design of the ship. Transverse watertight bulkheads cannot reasonably run through vehicle bays, however, bulkheads with large doors were placed in the middle of the lower vehicle decks to help prevent flooding in these areas. All vehicle decks were placed above the waterline and are 15 or 16 feet high. The heaviest of vehicles (M1A2 Tanks and AAAVs) were placed on the 2^{nd} deck, the lowest of the vehicle decks, for stability purposes. In order to achieve selective offload, the tanks and AAAVs on this deck were placed at angles to ease movement into or out of the traffic lane. While there are some vehicles that cannot be moved without moving others, once one or two of the blocking vehicle are moved, ease of offload increases. This 2^{nd} deck can be seen in the figure below:

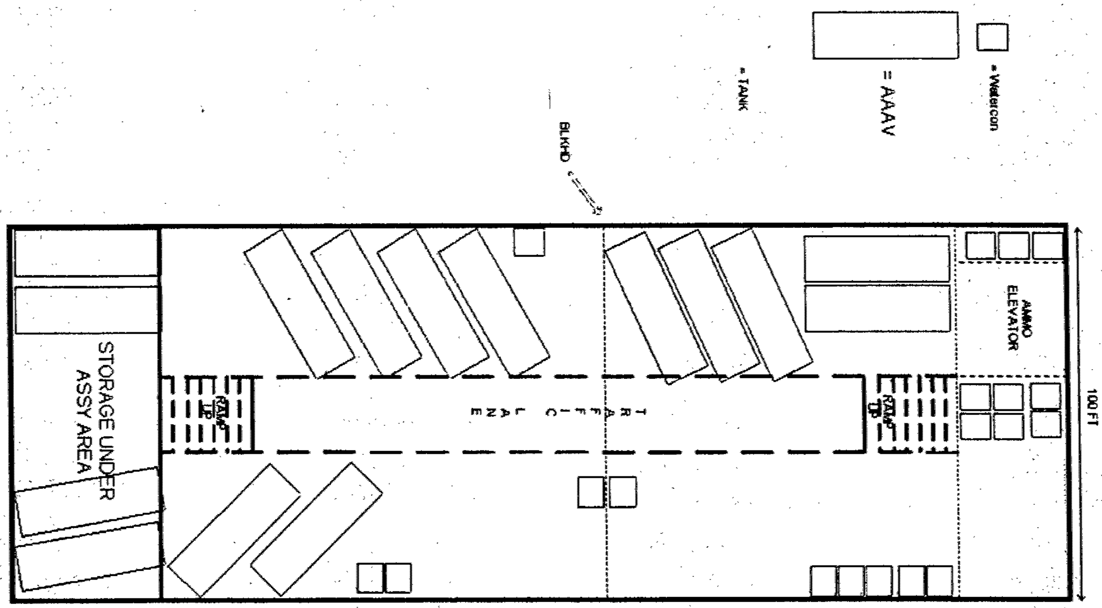


Figure 42. AAAV/Tank Deck (2nd Deck)

The 1st deck is just above the AAAV/Tank Deck and is of the same dimensions. This deck is on the same level as the assembly area permitting the vehicles to simply drive onto it while keeping clear of the ramps from the deck below. This deck holds a myriad of vehicles including RTCH, D7 Dozers, M-970 Refeuler, P-19s, M198 Howitzers, TRAMs and LAVs. The layout of this deck can be seen in Figure 43 below:

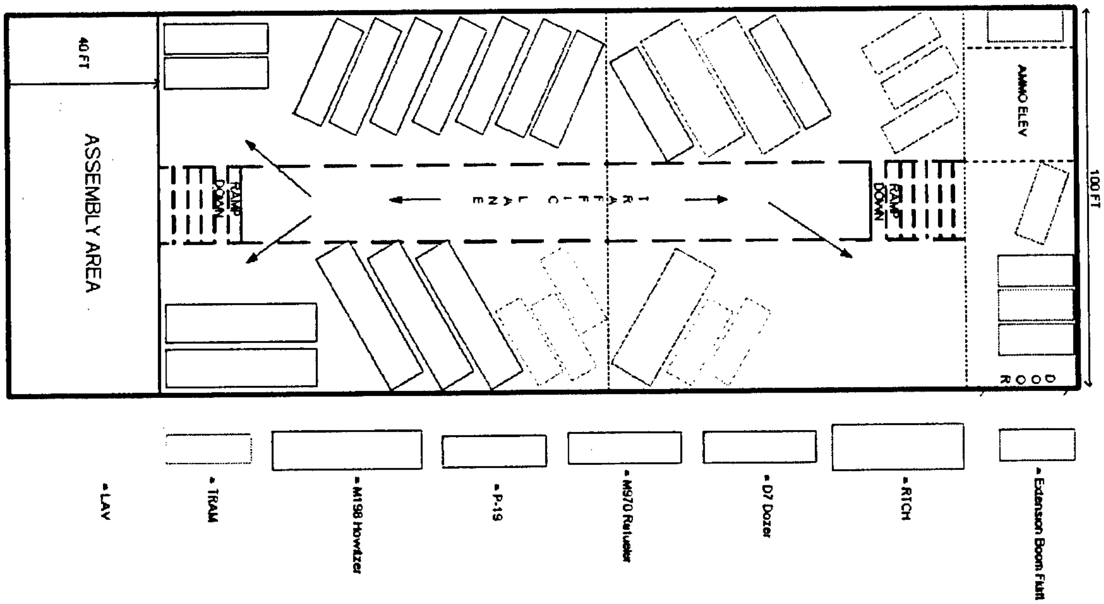


Figure 43. Misc. Vehicle Deck (1st Deck)

The third major vehicle storage deck is the main deck, just aft of the hangar bay. This deck houses the HMMWVs, the LVS Power Units and Trailers, the ROWPUs, MRC-110s, MRC-138s, MRC-142s and the 5 Ton Trucks. There is a ramp leading down to the Assembly Area from this deck on the port side between the well deck and the main hull. There is also an access door to the hangar bay on the starboard side. This deck is divided into two decks on the starboard side to accommodate for HMMWVs. The limited height of the HMMWV (4.5-6 feet) as compared to that of the other vehicles allowed for the split deck, where each of the split deck heights is approximately seven and a half feet. Just to the starboard side of the hangar bay entrance is a ramp leading to this second HMMWV deck. This deck can accommodate approximately half of the required HMMWVs. The layout of the main vehicle deck can be seen in the figure below:

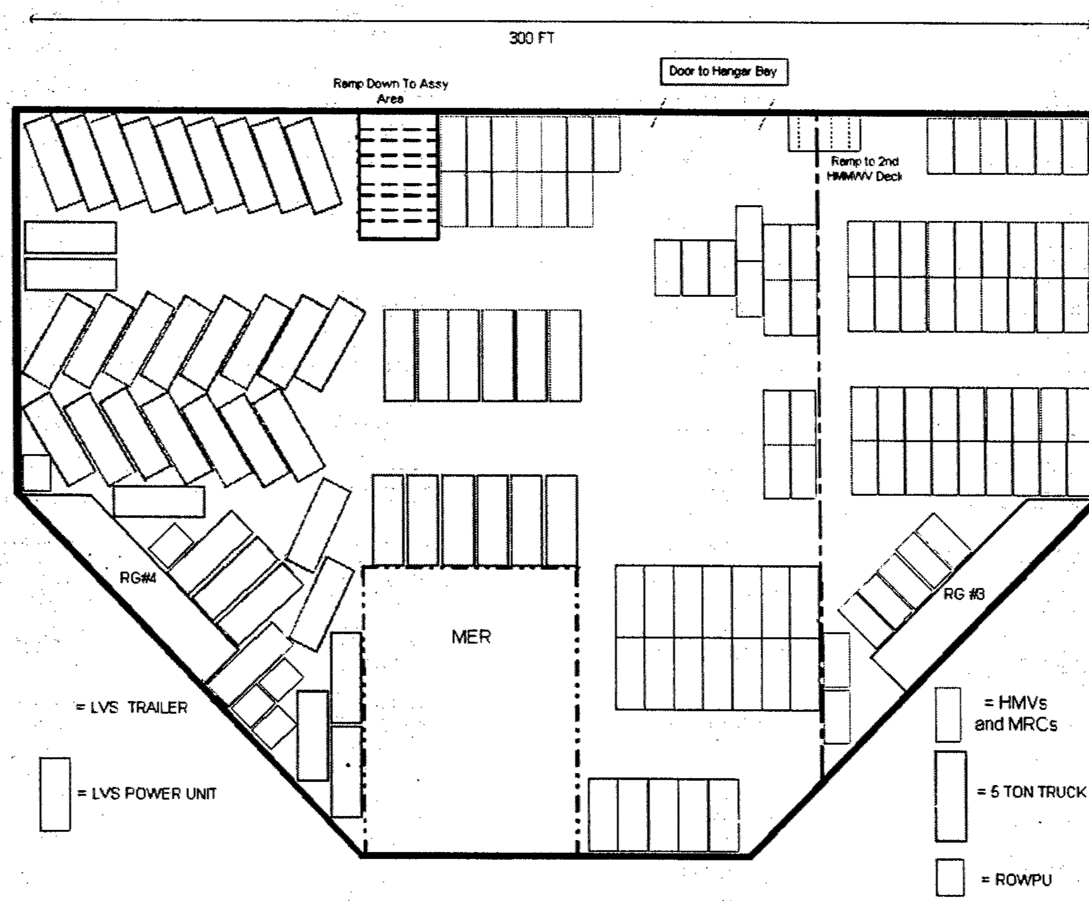


Figure 44. HMMWV/Truck Deck (Main Deck)

The vehicle decks described above total over 69,700 square feet of deck space. The free space between vehicles or in the gaps created from angling the vehicles seen in figures above was planned to be used for items that the team had to estimate measurements for such as cargo nets and other miscellaneous gear. Additionally, it is important to note that a Combat Cargo Officer or other qualified Marine loading officer might be better qualified to place vehicles in the decks allotted. The above figures show that it is possible to fit the large number of vehicles required while at the same time providing for some capability for selective offload.

4. Warehouse

Once the three major areas were set in the internal layout, the next most important consideration was in the cargo storage facility or ship's warehouse. Transfer of heavy cargo, including fully loaded ammunition containers of up to 24 LT, was a necessary capability of the ship. Therefore, the cargo storage area had to be easily accessible for storage of material received from other ships. This requirement drove the team to include the warehouse at the main deck level or above. In addition, a considerably large space with sufficient height was needed to store the predicted amount of cargo, as determined in earlier studies during the design process. Calculations were done to predict the required height of the space based on the estimated size of overhead cranes and stacking height of the cargo. The overhead cranes that were selected run on rails, which can twist at sea and disable the cranes. Thus, designs must be considered for the cranes rails such as using isolated mounts. The motion compensated crane system used to transfer shipping containers was placed just below the flight deck and has the capability of operating from the forward most part of the warehouse aft to the starboard elevator. The warehouse is 90 feet in length and extends almost the entire width of the ship from the main deck to the flight deck for a total volume of more than 960,000 cubic feet. Accessibility to the cargo storage area was a major design consideration for the ship. The two ammunition elevators were capable of stopping in the cargo area and were therefore sized to fit a standard shipping containers (8x8x20 feet). These elevators would be able to transfer cargo to the flight deck and vehicle decks, if needed. A corridor was placed along the port side of the ship leading from the warehouse to the hangar bay, with throughput capability

to either the aircraft elevators, the vehicle decks, or down the vehicle deck ramp to the well deck. The warehouse area can be seen in the figure below:

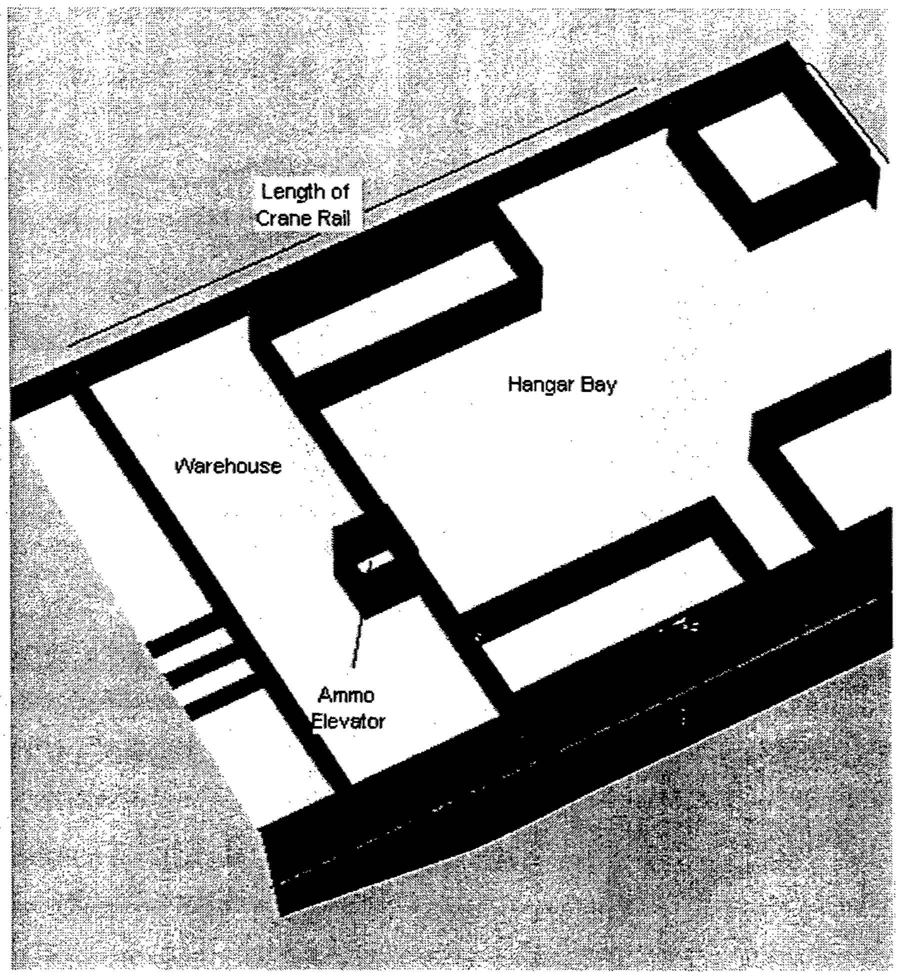


Figure 45. Warehouse Area

The remaining spaces considered in the internal layout above the waterline include Medical/Hospital facilities, Berthing, AIMD, Combat Systems spaces and BFIMA. All but the BFIMA are located on the decks in the forward and aft superstructure.

5. Medical/Hospital

Sea Force was designed with a medical and hospital facility equal to that of an LHD class ship and fully capable of providing Third echelon afloat care to the Sea Base. Each ship is configured to support a 500 bed hospital (80 intensive care, 20 recovery, 280 intermediate care, 120 light care) with six operating rooms and a pharmacy. Over 20,000 square feet of medical and hospital facilities were placed in the aft end of the ship adjacent to the hangar bay. This location was selected for ease of medical evacuation or embarkation. In addition, the Ground Combat Element (GCE) berthing is collocated with Medical in order to support medical overflow in the case of a humanitarian aid mission or other emergency. This added capacity increases the overall size of the medical and hospital facilities to much greater than a present day NESG. Figure 46 below shows the location of the medical and hospital facility on the O-3 Level aft:

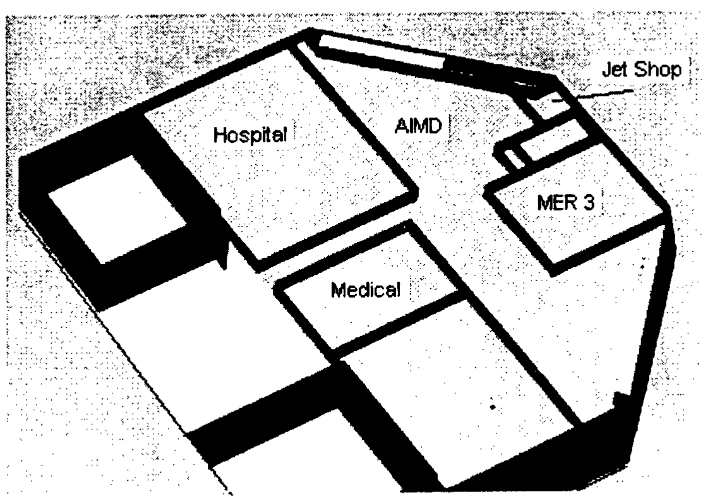


Figure 46. O-3 Level Aft

6. AIMD

The aviation capability in Sea Force's Aviation Combat Element (ACE) drives a huge need for intermediate maintenance, as with any big deck ship. As seen in Figure 46 above, the location selected for this facility was the O-3 level aft. The driving factor for this selection was a need to transport jet engines or other large aircraft parts to from the hangar bay or flight deck to the maintenance shop. The design incorporates a crane system in the hangar bay that can pick up an engine from a plane and place it on a trolley leading from the hangar bay to the AIMD shop on the O-3 level. AIMD occupies 34,380 square feet of space with a small portion dedicated to the jet shop at the very aft end. This location was selected so that jet exhaust could be easily expended during engine testing.

7. Berthing

Berthing requirements for Sea Force demand more volume than the vehicle decks alone, to include all messing and sanitary facilities. The berthing spaces were divided among the forward decks for the majority of the Marine forces and all Navy personnel. As discussed earlier, the GCE berthing spaces were placed in the aft portion of the ship to serve as medical overflow when the troops went ashore. In the forward berthing spaces, all CPO (Navy and Marine) and a portion of Marine officer berthing was placed on the O-2 level, Navy Officer and the remaining Marine officer berthing was placed on the O-1 level, the remaining Marine enlisted berthing was placed on the Main Deck with the ship's store, barber shop and post office, while the Navy enlisted berthing occupied the first deck. The

berthing was designed to support modularity concepts addressed in the Habitability section.

8. C4ISR

The defensive capability of Sea Force is driven by three major weapon systems, small caliber gun systems, and soft kill systems. Together with the combat systems spaces and sensors, over 265,000 cubic feet of the ship's volume, excluding the ship's ammunition stores, is dedicated to C4ISR. The majority of the command and control spaces are on the third deck forward of the warehouse. All flight deck control spaces to include flight ops control and the LSO video room are located in this area as well. Similar in design to and LHD class ship, the command and control spaces include JIC (Joint Intel Center), SSES (Ship's Signal Exploitation Space), TACLOG (Tactical logistics Ctr), HDC (Helo Direction Control), SACC (Supporting Arms Coord Center), CIC (CIC), TACC (Tactical Air Control Ctr), and LFOC (Landing Force Ops Center). Two Free Electrol Laser power modules are located on this deck at the port and starboard extreme beam, directly next to each laser. Just adjacent to these power modules, spaces are allotted for conex box insertion for SEAL and EOD team equipment or other organic/inorganic assets. The remaining area on the O-3 level forward is dedicated to joint or tactical planning spaces, required spaces to support next generation CEC, Electronic Warfare Integration, and Ship's Self Defense System. Weapon systems on the forward angled sides of the octagon include Rail Guns, Digital Array Radar Rooms, and NULKA launchers (Electronic Warfare systems). The remaining weapon systems are located at amidships on the beam (NULKA Launchers), aft on the angled sides of the octagon

(Rail Guns, DAR panels, Sea RAM), on the aft end (FEL), or above the bridge (Sea RAM, SPS-73 Radar). Various other frequency antennas are discussed more in the next section. The diagram below depicts several of the spaces described above.

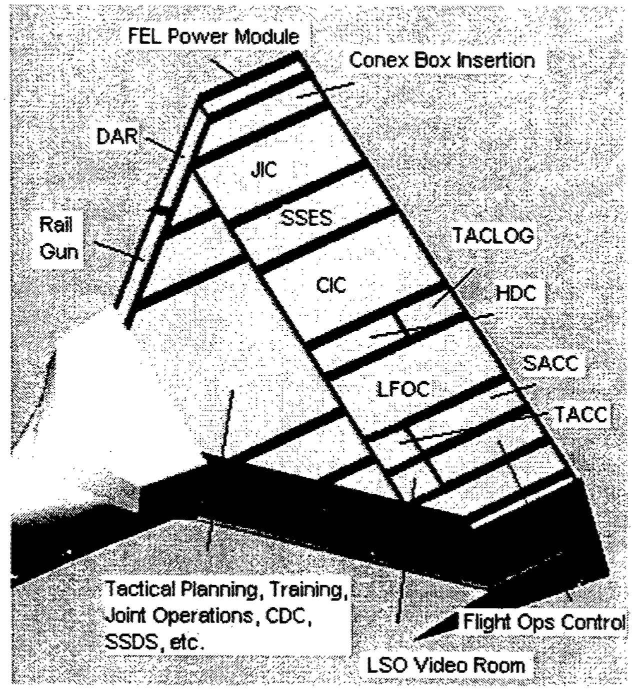


Figure 47. Combat Systems Space Layout

9. Intermediate Maintenance Activity

One of the requirements for Sea Force design was to serve as an intermediate level maintenance activity for the ships in company. This drives the need for a large Battle Force Intermediate Maintenance Activity or BFIMA. Over 16,000 square feet of maintenance space is incorporated into the layout forward of the two lower vehicle decks. It is accessible via the ammunition elevator for transfer of parts from the flight deck to the maintenance shop. This space is mainly divided into the hydraulics and pump repair shop, motor rewind shop, MR shop and pipe shop.

The aforementioned sections of the internal layout account for the spaces above the waterline. The following sections address those spaces below the waterline. The layout of these spaces in the main hull can be seen in the figure below:

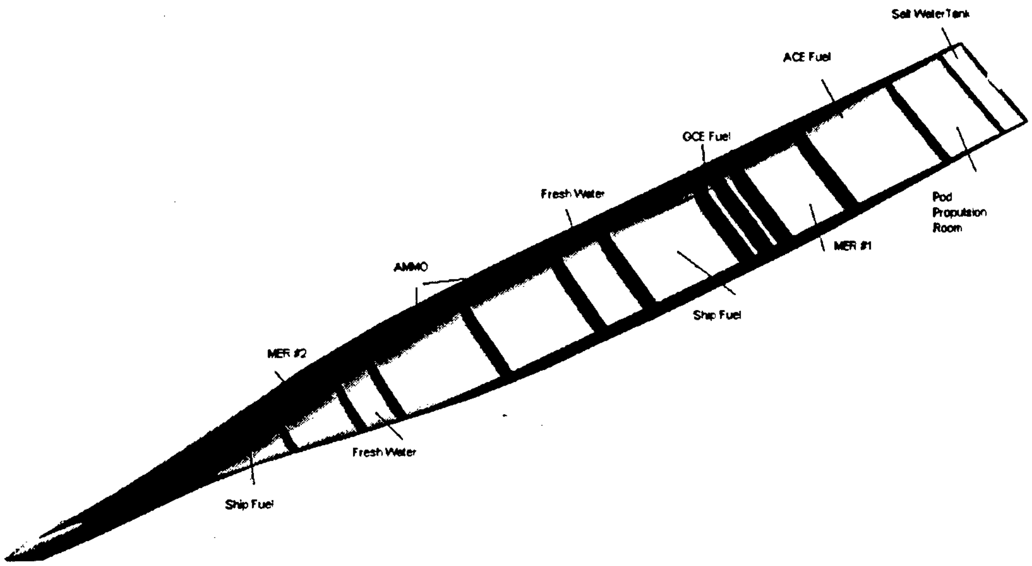


Figure 48. Main Hull Internal Layout

11. Tankage

Several factors must be taken into account when assessing the need for tanks in the hull. Due to the both the large size of the ship and the cargo it must carry to support a MEB operation for 30 days, the tank design is a tremendously important issue, especially given the ballasting requirements associated with simultaneous flight deck and well deck operations. Sea Force carries more than 12,000 tons of Marine Corps cargo, most of which is offloaded during an amphibious operation. Once this cargo leaves the ship, ballast tanks must be available to maintain a specific draft and keep the ship at an even list and trim. The level of draft is very important because the well deck is a dry well and must remain at the

waterline to facilitate LCAC and AAAV operations. Thus, at least 12,000 tons of ballast that was evenly distributed along the hull tanks had to be included in the design in order to minimize loading stress after maximum ballasting had occurred. The tanks were properly distributed between the outrigger hulls and the center hull to avoid large stresses in the ship structure, especially on the beams that connected them. The tanks could not all be placed in the outriggers as they would have gained more than 10,000 LT of weight.

The division of the tanks below the waterline fell hand in hand with watertight bulkhead placement. Numerous considerations were made when placing tanks. The fuel tanks were seawater compensated, so there was no affect on the trim of the ship as fuel was consumed. However, with approximately 4,000 LT of vehicle and aircraft fuel and 8,000 LT of ship fuel, the fuel tanks accounted for a significant amount of weight. Efforts were made to distribute them symmetrically about the longitudinal center of flotation. Additionally, fuel tanks had to be protected from damage. The fuel associated with the aviation assets and GCE (Ground Combat Element) was critical and was placed in the main hull. Ship fuel also required protection. However, given the large amount of ship fuel compared to MEB fuel, the decision was made to place some of it in the outer hulls. The outrigger hulls were designed to protect the main hull from damage. While putting fuel in this area was dangerous, the decision was made to put small fuel tanks in the outriggers at locations that were not adjacent to the engine rooms or the magazine in the main hull.

The remaining hull volume in the outer hulls provided much needed liquid storage space. Fresh water tanks, sewage tanks and the previously mentioned ballast tanks were all placed in

the outer hulls. Increasing the amount of tank space, along with increasing the number of compartments in each outrigger, led to better protection from flooding. Due to the placement of the outriggers so far out off the ship's centerline, flooding either of them had a much larger affect on the heel of the vessel then flooding of the center hull. A combination of nearly full tanks and voids filled with lightweight foam or other material to achieve a near 100 percent permeability was used to eliminate the flooding concern for the outriggers. This design ensured that severe damage could be taken in the outriggers without a significant affect on the list of the vessel. In the case of the ballast tanks, which are large and empty before the ship offloads equipment, flooding in one side can be compensated for by ballasting down the other side. The ballast tanks are symmetrical, allowing the ship to absorb several feet of additional draft and still remain operational.

12. Ammunition

The Sea Force design incorporates one magazine into the main hull that is broken up into two separate compartments, each with two levels. Together, these four spaces contain all of the ordinance carried by the ship, with the exception of that loaded into the ship's weapon systems. Additionally, the rail gun spaces incorporate a magazine under the gun machinery space. Thus, the rail gun ammunition is not accounted for in the main ammunition compartment. Each space has elevator access to only one elevator because there is a transverse watertight bulkhead between the two compartments. The elevators are offset from centerline, so they do not interfere with the traffic lanes on vehicle decks above. The elevators stop at both lower vehicle decks (and BFIMA), as well as the warehouse (where ammunition is onloaded), and go all the way to the flight deck. There are

doors on the flight deck, so that the elevator can be down without interfering with flight deck operations.

13. Engineering spaces

The Sea Force power plant was designed so that if ship was stuck in port, a small gas turbine could efficiently supply sufficient power. Because of IPS, there were several electrical distribution centers, each of which received power from all three engine rooms. Engine room placement was done to maximize survivability, minimize inlet and exhaust ducting, and make engine accessibility better for repair. The Largest engine room is located on the main deck with one LM6000 and one LM2500+. While these engines are easily removable and are in a vulnerable location, they are not susceptible to flooding. The remaining two engine rooms were placed below the waterline, with significant space between them.

All auxiliary systems were placed in the lower machinery rooms. Sewage system tanks were placed on the outriggers to increase the amount of (nearly) inert tankage. With the Integrated Power System, the ship's power is derived from the same source as the propulsion system. Water is made through a reverse osmosis desalination plant. HVAC of the ship is done through hot water and chill water circulation systems.

D. COMBAT SYSTEMS

The primary mission of the Sea Base ship will be to support Marine Expeditionary Forces in the execution of Ship to Objective Maneuver (STOM). Based on this requirement, the ship

will not be required to have a robust offensive capability. The Combat Systems suite, with the exception of the Naval Surface Fire Support Capability, was designed to be defensive in nature, focusing on the following threats: High-density missile and small boat attacks, floating, bottom and surface moored mines and coastal water submarines. To further enhance the ship's ability to counter the above threats, a robust C4ISR capability will be required to support the Expeditionary Forces ashore. Additionally, the ship must be capable of being upgraded to become a Joint Command Center (JCC) in theater.

To meet the above requirements, the Sea Force will utilize a layered, self-defense concept to defeat the common threats encountered in Littoral Warfare. The ship will have a limited offensive capability with the exception of Naval Surface Fire Support, which will be used for fire support. In the event of any major air, surface and/or sub-surface threat, battle group assets will be required to escort the Sea Force. The Sea Force will not commence STOM operations until the operating area is cleared of the main bulk of enemy air, surface, subsurface and mine threats. Before proceeding with the discussion of the combat systems and C4ISR architecture, it should be noted that the systems described below would be based on Year 2020 technology. Since the exact technology available in the year 2020 is unknown, systems currently in use or in development will be used to describe the desired types of capabilities on Sea Force. The systems employed on Sea Force will be similar to the ones listed below, but they absolutely will NOT be the same systems installed on Sea Force.

1. Overall Architecture

The combat system and C4ISR suites will be fully integrated to include both organic and non-organic sensor inputs. The integration of the C4ISR and combat systems will allow the Sea Force to be Network Centric Warfare capable and will give the ship the ability to provide both power projection and ship self-defense. The backbone of the combat systems architecture will be the Year 2020 Generation Cooperative Engagement Capability (CEC) and Year 2020 Generation Ship Self-Defense System. The CEC system will integrate all organic and non-organic sensor inputs and provide tracking on all targets in the battle group based on the sensor with the best track quality. The SSDS envisioned for the ship will ensure that all organic weapons will be linked to provide the layered, self-defense of the ship. The SSDS will take the sensor data provided by CEC and then enable the watch stander to effectively defend the ship utilizing the best weapon for the task.

Using CEC and SSDS as the underlying architecture, the ship's sensors, C4ISR and weapons capabilities will then be added. The ship's sensors must provide all data for tracking of friendly and/or enemy aircraft, missiles, mines, surface vessels and submarines. The C4ISR suite must be capable of gathering data from both onboard and battle group assets. The weapon systems onboard must be capable, at a minimum, of defeating Anti-Ship Cruise Missiles, small to medium sized boats, mines and even be capable of self-defense against an undersea threat.

2. C4ISR

As stated previously, the design of the ship must include a state-of-the-art C4ISR suite to give the ship the ability to act as the Joint Command Center while in theater and to support the requirements of STOM. The more difficult of the two requirements will be to give the Sea Force the ability to act as the Joint Command Center in theater. First, the ship must allocate room for the embarked staff and their operators. The staff and their operators are anticipated to be as large as 600 personnel. The sheer number of people will consume a considerable volume within the ship for both working and living spaces.

The second major hurdle, and certainly the more challenging one, will be allocating the required space for all of the electronic equipment and associated antennas. While the internal equipment will consume a large internal volume, the antennas will need topside placement. The Sea Force has a large area for mounting antennas on the side of the flight deck, but considerations such as antenna spacing and placement need to be addressed. The greatest obstacle will be ensuring all of the antennas can be placed properly without a tower. All current big deck and aircraft carrier designs have a superstructure to mount antennas, but the Sea Force was created without this tower placing additional constraints on the C4ISR design.

While sufficient time was not available to fully address these concerns, an estimate of the communication suite requirements was completed. A calculation of the number of antennas required to be placed topside was made based on the number of embarked Marine vehicles, aircraft and other required ship-to-ship and ship-to-shore communications. As can be seen

below in Table 17, the actual number of required antennas will be substantial. The high number should quickly give one a feel for how difficult it may be to place all the antennas properly ensuring proper separation and orientation without the benefits of a tower on the flight deck. The number of antennas listed in the table assumes that each antenna will be able to handle four simultaneous communications through the use of multiplexers. The number of simultaneous channels handles by each antenna may vary based on frequency and technological capability available during ship construction [40].

Frequency Band	**Quantity of Antennas**	**Purpose**
VHF	9	Tactical Voice Communications, Aircraft Communications
UHF LOS	9	Aircraft Communications
UHF SATCOM	9	IXS, CUDIX, NAVMACS, TACINTEL, (Command LAV's, LAVP7, M1A1, HMMWV, Armed HMMWV), LCACS, UAV's and LCU's
SHF	6	GCCS, SIPRNET, NIPRNET, VTC, JWICS
EHF	4	Secure Voice and Strike Voice/Data
HF	9	Expeditionary Forces, Fire Support
TACAN	4	Aircraft Safety and Navigation
GPS	4	Navigation
IFF	2	Aircraft Identification
Various Whip	Unknown	Voice/Data links
Total	**56+**	**Minimum Required Number of Antennas**

Table 17. Major Antennas for SEA FORCE

In addition to ensuring the Sea Force will be capable of acting as a JCC ship, the Sea Force will still require many of the above listed C4ISR capabilities to support STOM. These forces must have every advantage when planning and implementing

incursions to their objectives. To ensure the safety and effectiveness of the embarked forces, the ship will utilize many different systems such as GCCS-M, NTCSS, NAVSSI, and an Expeditionary Sensor Grid. These resources will give the ship the means to keep a current picture of the battle space. The information can then be processed and re-distributed to forces afloat and ashore.

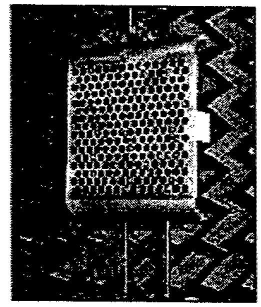
3. Air Warfare

Air Warfare was the first area considered in the Combat Systems design spiral. While missiles could very well be launched from aircraft in a Littoral scenario, the more likely situation was deemed to be a land based missile attack. This attack could come in two forms: a temporal saturation or a magazine saturation. A temporal saturation would be a massive missile attack meant to overwhelm the number of simultaneous missile attacks that could be handled by on board systems. An example would be a system that could engage eight missiles simultaneously, therefore, the enemy fires ten missiles at once. Magazine saturation is defined as an attack of a few missiles (i.e. 5 to 8 missiles) that would be repeated over the course of many hours and/or days. The goal is to deplete the enemy ship's magazine and then make the kill. An example would be firing 101 missiles that the enemy ship has only 100 missiles on board. Obviously, the last missile would make hit the target baring a mechanical or other problem.

a. Sensors

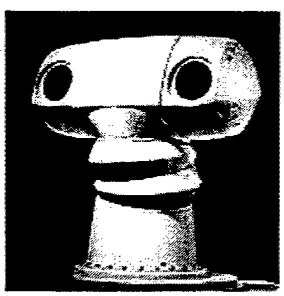
To deal with the possibility of high density missile

attacks, the Sea Force will employ a Year 2020 Digital Array Radar which will be utilized for Volume Search, Tracking and Fire Control. This radar system will be ideal for tracking dozens of simultaneous targets and providing fire control solutions as appropriate. The ship will utilize four arrays which provide 360 degree coverage to within ~100 feet of the ship. The Volume Search/Digital Array Radar (see figure to the right) for the ship must provide ranges up to 250 km for not only tracking of enemy air targets but friendly air targets as well. The coastal environment will be filled with many different types of aircraft to include friendly, enemy and commercial aircraft and management of all these tracks will be essential [41].



Digital Array Radar Panel Under Development

The Digital Array Radar will be the primary sensor for track and fire control data, but as with any naval system, there must be another system for redundancy. The Digital Array Radar will be backed up by the Year 2020 Generation Infrared Search and Track System (IRST). The IRST provides an excellent secondary sensor for both tracking and fire control. Four IRST sensors will be used primarily for detecting the plumes of missile exhaust. Once the exhaust has been detected, a weapon can be slewed to destroy the target. The IRST must be designed to have a range of at least 10 km to be used with on board weapons.



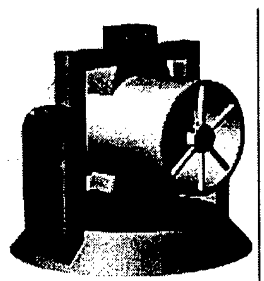
Current IRST Sensor

While the Digital Array Radar and IRST will be used as primary and secondary tracking/fire control solutions against air tracks, other systems will be required to help manage the coastal air picture. To handle the sheer volume of air traffic

found in the littorals, a year 2020 Generation Identification Friend or Foe (IFF) system will be equipped. The IFF system will allow friendly, commercial and other tracks to be identified at long ranges (up 150 km) and further assist the ship in track management. Another system that will be required on board will be the Tactical Aid to Navigation (TACAN) system. TACAN is a requirement for ships that will operate with aircraft. TACAN allows friendly aircraft to locate and fly directly to the ship's position [42].

b. Weapons

To combat magazine and temporal saturation attacks, two types of weapon systems will be used: The Free Electron Laser and a Year 2020 Generation SEA RAM. The Free Electron Lasers will provide an effective counter to magazine saturation attacks due to its deep magazine. As long as the system is operational, it can fire without the threat of using all of its rounds. The ship will be configured with five beam directors and three beam generators. Since there are only three beam generators, a maximum of three beam directors can be utilized at any one time. Any three out of the five can be utilized, however, by simply re-routing the beam to any one of the beam directors. The Free Electron Laser (FEL) will be expected to have a range of at least 10 km. This range allows defense of the ship against six simultaneous incoming cruise missiles traveling at about Mach 2 [43].



FEL Beam Director

The SEA RAM will be the secondary Air Defense weapon installed on board. The SEA RAM will help counter the temporal saturation attack

Current SEA RAM

scenario. While the SEA RAM has less than half the range of the FEL, the missile defense system will give the ship the ability to engage more than one target at a time. The capability of the SEA RAM to engage more than one target at a time will effectively complement the FEL. There will be three SEA RAM mounts on board and they will be spaced as far from the FEL directors as possible in the event the ship sustains damage. The minimum range of the SEA RAM will be 4 km (current capability), but with technological advancements, the range should be extended out to 10 km making it a much more effective weapon.

As stated previously, the combat systems suite will be primarily defensive in nature and as such features mainly point defense weapons. For additional protection from air threats, three other options arise: Battle Group Escorts, Embarked/Battle Group Aircraft and Electronic Jamming/Deception Capability. While the Navy recently canceled the Advanced Integrated Electronic Warfare System (AIEWS), the assumption will be made that a similar program with more advanced capabilities will be re-instated by the Year 2020. The electronic warfare capabilities added with this system will give the ship an active jamming capability and perhaps even a decoy system for use onboard the ship (provided the radar cross section can be reduced to an acceptable level vs. size). Other defense against air attack will come in the form of air defense capabilities on other battle group assets as well as from embarked aircraft such as the Joint Strike Fighter. These other assets, if required, must protect the Sea Force from ranges greater than 10 km and preferably out to a range of 100 km+. For a layout of the air self-defense suite, refer to Table 18 below.

Layer	Weapon System	Range (km)
Outer/Middle/ Inner Layer Defense	Embarked JSF's Battle Group Air/Surface Assets	10-100+
Point Defense	Free Electron Laser Enhanced SEA RAM Active Electronic Warfare Countermeasures Decoys	0-10

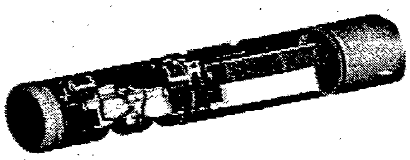
Table 18. Layered Air Defense for Sea Force

4. Mine Interdiction Warfare

With the air threat capabilities defined, the next concern will be the mine warfare threat. For Littoral warfare, this area must not be overlooked as mining of coastal waters is and will be an excellent defensive for the enemy. Even though Mine Warfare was discussed after Air Warfare, it will be no less important in the combat systems design. Using the premise that the combat system suite would not contain any robust offensive capabilities, the decision was made to only enable the ship to perform basic mine detection, clearance and removal operations. The ship would not knowingly steam into heavily mine infested waters without assistance from battle group assets such as mine hunting ships. The ship would be enabled, however, with basic mine detection and removal equipment in the event of the non-availability of battle group assets or small scale mine threats. The requirement to operate in a Littoral environment dictates that some mine detection capability be retained onboard or simply the mention of a mine threat might make the ship incapable of conducting its mission.

The primary mine detection and removal assets for the Sea Force will be the embarked aircraft equipped with mine detection/removal equipment. The aircraft to be used for the Mine Interdiction Warfare Mission (MIW) will be embarked Year 2020 Generation SH-60 aircraft or an appropriately configured MV-22's. While the MV-22 is not currently envisioned for any mission other than to carry marines and other cargo, the assumption will be made that without an SH-60 aircraft on board, an MV-22 or other hover-type aircraft will be equipped to carry out MIW.

The types of equipment to be used mounted in these aircraft include such systems as the Airborne Laser Mine Detection System (ALMDS) or the Rapid Airborne Mine Clearance System (RAMICS). The ALMDS will be mounted to the fuselage of the aircraft and use a laser to penetrate the water to about 15 meters. The system will be used to search for floating and surface mines.



ALMDS Module

The RAMICS will be integrated with the ALMDS. Once the mines have been detected, a 30mm cannon will fire super-cavitating rounds to destroy the mines. While this may not be the exact system in use for MIW in the future, the system utilized will certainly be similar in design.

In addition to the aircraft, Unmanned Undersea Vehicles or UUV's will also be utilized. As will be the case with Aircraft mounted MIW equipment, UUV's will allow the ship to stay safely out of the suspected mine area (at least 10 km). These autonomous undersea vehicles will be launched from the ship, detect mines and/or ensure their destruction. Some current systems include the Long Term Mine Reconnaissance Systems (LMRS), the Remote Minehunting System (RMS) and the Enhanced Mine Neutralization System (EMNS) [44].

5. Surface Warfare

Surface Warfare will be the final of the three warfare areas of concern. Similar to Air and Mine Warfare, defense against small boat attacks will be of primary importance in the coastal environment. In the past, the Navy has concentrated on weapon systems to win engagements that focus on combatant-to-combatant or warship versus warship type scenarios. In this environment, the concern will be a small boat or groups of small boats attempting to disrupt operations by cause damage to the Sea Force. Like a high-density missile attack, swarms of small boats may attempt to overwhelm the ship's defenses and cause enough damage to inflict a mission kill. To further complicate defeating a small boat threat, these boats may attempt to hide among non-combatants such as fishing or merchant vessels rendering conventional weapons useless. To defeat the small boat threat, new generation of missiles and weapons will be utilized.

a. Sensors

To deal with the possibility of high-density small boat attacks, several different sensors will be utilized. The primary surface search and navigation radar will be a Year 2020 Generation equivalent SPS-73 radar. The surface search and navigation radar must be capable of providing detection of small surface vessels and have the ability to be tuned for navigational use. The required range of the radar will be comparable to today's surface radars that have a minimum of about 24 km (~horizon) and extend out to about 119 km (weather and other conditions permitting).

The Digital Array Radar will be used in conjunction with Electro-Optical Systems for primary and secondary tracking and fire control. The Year 2020 Digital Array Radar will be ideal for tracking the numerous surface targets that will be present in the littoral environment. The ship will utilize four arrays which provide 360 degree coverage to within ~100 feet of the ship. The Volume Search/Digital Array Radar for the ship must provide ranges of at least 10 km for tracking of friendly and enemy surface targets.

In the event that a surface vessel is lost in sea clutter, a small boat in rough seas for example, the installed electro-optical system will be used as backup. The Infrared Search and Track System will be used as the primary electro-optical sensor. Secondary electro-optical systems, cost permitting, may include the Year 2020 Generation Thermal Infrared Sensor System (TISS) or Forward Looking Infrared Radar (FLIR). These systems will provide an excellent complement to the Digital Array radar by allowing even the smallest of vessels to be discerned from the surroundings.

b. Weapons

A new breed of weapon will be required to combat the possibility of high-density, small boat attacks and/or small boats attempting to protect themselves among non-combatants. The weapon must not only be able to disable multiple targets quickly, but its effects must be focused. These requirements can be met using several different types of weapons. These weapons include the Year 2020 Generation SEA RAM, the Free Electron Laser, and an Electromagnetic Rail Gun.

The inner-most defense of the ship will be the SEA RAM and the Free Electron Laser. The current SEA RAM provides defense out to 4 km against air targets only. By the year 2020, however, it

is anticipated that the SEA RAM will not only have an additional surface mode, but that the system will have a range on the order of about 10 km. The SEA RAM will be used primarily against small boats and medium sized surface vessels for mission kill. The weapon will cause minimal effect on larger combatant and big deck ships and should be used primarily against ships clear of non-combatant vessels.

The next weapon in the layered surface defense will be the Free Electron Laser. The Free Electron layer will provide coverage out to 10 km and will be used for precision shots. The FEL is ideal for disabling small boats attempting to find cover in a group of non-combatant vessels. The FEL can be used to burn holes into exposed weapon systems, engines or the hull itself without endangering nearby fishing, merchant or nearby pleasure craft.

To provide a capability against larger vessels, the Electromagnetic Rail Gun can be fired line of sight. Armor penetrating or fragmentation rounds can be fired to disable or provide mission kills on a vessel. Four Rail Gun mounts will be placed on the four diagonal corners of the ship to provide 360° coverage out to the horizon or about 24 km. While the rail gun will be utilized primarily for Fire Support Capability, it provides a redundant weapon for use in Surface Warfare.

To provide a surface defense at ranges of greater than 24 km, embarked Joint Strike Fighters, SH-60's or MV-22 equipped aircraft could provide protection. The Joint Strike Fighter could utilize its gun or any loaded bombs to perform the surface mission against larger surface combatant or big decks. If the embarked aircraft are being utilized for STOM, other battle group weapons and aircraft will be used to provide surface coverage.

Layer	Weapon System	Range (km)
Outer/Middle/ Layer Defense	Embarked JSF's Battle Group Air/Surface Assets	24-100+
Inner Layer	Electromagnetic Rail Gun	10-24
Point Defense	Free Electron Laser Electromagnetic Rail Gun Enhanced SEA RAM Active Electronic Warfare Countermeasures Decoys	0-10

Table 19. Layered Surface Defense for Sea Base Ship

6. Undersea Warfare

The Undersea Warfare capability will be minimal on the Sea Force. If a major undersea threat exists, the Sea Force will be placed at a safe standoff distance and battle group assets will be utilized to hunt and neutralize the threat. To incorporate an extensive Undersea threat on the Sea Force would drive up the cost not to mention place a vital asset, intended solely for STOM, at risk of serious damage or sinking. To provide a basic defensive capability so the ship can clear the area, aircraft mounted dipping sonars and UUV's will be utilized.

a. Sensors

The SH-60 and/or MV-22 configured aircraft along with Unmanned Undersea Vehicles will be utilized in the presence of an undersea threat. The aircraft and/or UUV's will be deployed to attempt to locate, track and possibly neutralize any

potential undersea threat. The Sea Force will then proceed out of the area until the threat is neutralized. The Sea Force will absolutely not be utilized to attempt to localize and neutralize a threat with onboard systems.

b. Weapons

Once a track has been localized and tracked with an appropriate fire control solution, the aircraft and/or UUV's will be equipped with Year 2020 Generation MK46/50 torpedoes. These will be the only weapons available to the Sea Force in the event of an undersea threat. If additional assets are required, additional battle group assets will be required to include aircraft, submarines, aircraft and ships.

Layer	Weapon System	Range (km)
Outer	Battle Group Submarines, Air and Surface Assets	100+
Middle/Inner and Point Defense Layer	Unmanned Undersea Vehicles SH-60 and/or MV-22's	0-100

Table 20. Layered Undersea Defense for Sea Force

7. Electronic Warfare

The Sea Force will incorporate the latest electronic warfare (EW) capabilities. These capabilities will include Year 2020 Generation Electronic Support (ES), Electronic Attack (EA), the IRST and a decoy system. These capabilities will help aid the ship in defending itself against anti-ship cruise missiles (ASCM), jamming attacks from the enemy as well as the ability to detect the enemy via the electronic spectrum. The overall architecture of EW will be provided by the Year 2020 version of

the Advanced Integrated Electronic Warfare System (AIEWS). The Navy recently canceled the program, but it is anticipated a newer version of the system will be resurrected in the near future. The AIEWS will then be fully integrated with the CEC and SSDS systems allowing its whenever the threat requires it. The types of systems that will be integrated with this suite will be Year 2020 version of the SLQ-32(V), both active and passive parts of the system, and a decoy system such as the MK53 NULKA decoy or Super Rapid Blooming Onboard Chaff System.

8. Naval Surface Fire Support

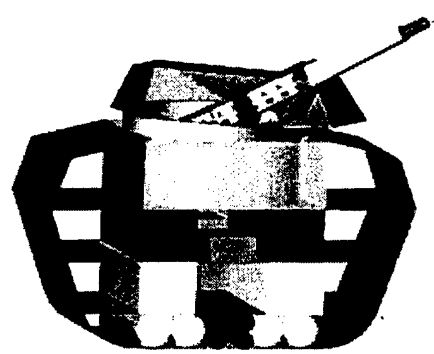
The ship will be primarily defensive in nature with the exception of the Naval Surface Fire Capability. While the ship will feature the Joint Strike Fighter for Close Air Support, a redundant NSFS capability will be included, pending Rail Gun final cost estimates. The final decision to include Rail Guns was deemed necessary because it provides additional redundancy for other warfare areas. Three major reasons for inclusion of the rail gun are: ability to operate independently, provides a redundant weapon for use against surface threats and the rail gun will provide a long range strike capability extending all the way to the objective (~200 NM inland).

The rail gun, while expensive, gives the ship the ability to perform STOM without the assistance of battle group assets. If a large amount of fire power is required at the objective, or enroute to the objective, the ship will be capable of providing this support with the embarked Joint Strike Fighters and the Rail Gun. No other battle group assets will be required to assist the Sea Force in its mission.

In addition to allowing the Sea Force to operate independently, the rail gun provides an additional defense against surface threats. Without the rail gun, another weapon would need to be included on Sea Force to provide redundancy for Surface Defense. Including the rail gun helps to offset costs by covering multiple requirements with one system, in this case, NSFS and a surface warfare backup weapon.

Another key capability of the rail gun will be its ability to strike at targets from great distances thus acting as another "squadron" of JSF's. One example would be a situation in which the embarked expeditionary forces were required to accomplish missions in three geographically different areas simultaneously. The Joint Strike Fighters could be split between two of the objectives for close air support, while the third target area, would be covered by the Rail Guns. While there will certainly be a cost argument for including the rail guns, there is little argument that the rail guns vastly improve the capabilities of the ship to conduct its mission.

A conceptual rail gun is shown to the right. The gun has been modularized to take about around the same amount of volume as the 5" gun. The module includes power banks, a magazine as well as the gun and barrel training mechanisms. On the Sea Force, four mounts positioned will be positioned at the four corners of the ship. These mounts can then be utilized two at a time, port or starboard. All four mounts cannot be utilized simultaneously because of the power demand on the ship. The Rail Gun is expected to have a range up to 400 NM giving it the



NSWC Dahlgren Conceptual Rail Gun Design

ability to launch from about 200 NM offshore and reach objectives up to 200NM inland [45].

9. Combat Systems General Arrangement Plan

The arrangement of combat systems onboard Sea Force utilized the following design principles ranked by importance: Placement and volume of weapons and sensors to optimize Ship-to-Objective Maneuver, Survivability, Automation, Maintainability, Reliability, and Upgradeability/Affordability through the use of Commercial Off-the-Shelf (COTS) Equipment.

The most difficult task of the combat suite design was implementing a combat system that would not obstruct the flight deck or any STOM requirements. To facilitate keeping a clear flight deck, the tower was eliminated making antenna and radar placement much more difficult. Additionally, all weapon systems had to be mounted along the sides of the ship to avoid interfering with flight operations. The lack of a tower further increased the difficulty of making the Sea Force a Joint Command Center.

The combat systems suite, despite the above restrictions, was designed in accordance with the above requirements. While some of the restrictions did pose difficulties, the entire planned suite was implemented with the exception of the antenna layout. If sufficient time were available, a more careful layout of antennas and their separation would be performed. This analysis must be conducted before utilizing Sea Force as a Joint Command Center.

10. Survivability Analysis

At 150km, it has been assumed that the Joint Strike Fighter can engage threat aircraft or surface based missile launching sights. The JSF has the probability of killing half of these aircraft and half of any launched missiles. The total probability of the JSF against the aircraft and missiles is:

$$P_{K-JSF} = 1 - 0.6 \times 0.6 = .64$$

The Joint Strike Fighter will provide coverage for the ship to a range of about 10 km. Inside this envelope, the Free Electron Laser and Year 2020 Generation SEA RAM will be responsible for protection of the ship. For the FEL, the reliability will be based on the beam director's ability to track the target and the proper functioning of each individual component. A figure of 85% has been assigned to the FEL. The lethality will be assumed to be 100%. The total kill probability will be:

$$P_{K-FEL} = .85 \times 1.0 = .85$$

For the SEA RAM, the Surface-to-Surface missile is assumed to have a reliability of 85% and a warhead lethality (given a hit) of .70. The single shot kill probability against an ASCM will be:

$$P_{K-SSRAM} = .85 \times 0.7 = .595$$

Since killing an incoming missile will not be assured, it may be prudent to fire two SEA RAM missiles to ensure a higher kill probability, this will then enable the SEA RAM to have kill probability against an ASCM of:

$$P_{K-SSRAM} = 1 - (1 - 0.595)^2 = .8359$$

To account for the electronic warfare systems, a probability of kill against anti-ship cruise missiles will be 0.5.

Having accounted for all air defense systems, the total effectiveness for the self-defense layer can be assessed. The effectiveness can be estimated to be:

$$P_{K\text{-}TOTAL} = 1-(1-P_{K\text{-}JSF})(1-P_{K\text{-}FEL})(1-P_{K\text{-}RAM})(1-P_{K\text{-}EW})$$

$$P_{K\text{-}TOTAL} = 1-(1-0.64)(1-0.85)(1-0.8359)(1-0.5)$$

$$= 0.996$$

A maximum credible attack would involve 50 ASCMs, the possibility of one or more missiles leaking through the defensive layer will be:

$$P_{LEAKAGE} = 1-0.996^{50} = 0.182$$

Given this value, the Sea Force would have an 18% chance of being struck by a missile, but the side hulls will give a great advantage over mono-hull ships. The side-hulls of the trimaran will allow the ship to sustain more missile hits than a conventional carrier or big deck amphibious platform. The protection the side hulls provide was another driver in the design decision to build a trimaran ship [46].

11. Combat Engagement Flow

Having fully described the combat systems design process, its layout and effectiveness, a proposed engagement flow for employing the weapons and sensors will be described.

a. Air Defense

The air defenses will begin by detecting a target through one or more of several different methods. At ranges of 100km+, the Digital Array Radar will be able to gain a track on an unknown threat. The operator onboard will then be able to utilize ownship aircraft, IFF or another ship's information on

the track to identify. As the air track closes the vessel, additional sensors such as the electronic warfare suite could attempt to correlate the track based on its emissions. If the track is finally identified as hostile, it will be designated as such by the operators. At ranges in excess of 10km, any available Joint Strike Fighters or other battle group fighters can be vectored to the target to engage. If no aircraft are available, the ship can wait for the target to close within 10km. At this point, the Digital Array Radar, SEA RAM radar and/or the Infrared Search and Track System can then be used to maintain track and pass a fire control solution to the Free Electron Laser or SEA RAM. The FEL and SEA RAM may then engage the target and await a kill. If multiple inbound missiles are present the FEL, SEA RAM and onboard decoy systems could be used simultaneously to attempt to defeat the inbound threats. As shown above, the weapon systems onboard have a high probability of defeating the threat with only 18%, or 9 missiles out of every fifty simultaneous inbound missiles reaching the ship.

b. Surface Engagements

Similar to the Air Defense Sequence, surface targets will initially be detected by the Digital Array Radar at ranges greater than 50km. The operators will then begin to assess the potential threat of the unknown target via Electronic Support, embarked or battle group aircraft or other friendly ships in the area. Once the ship has been identified, and providing it is hostile, aircraft can be vectored to the position to engage. If these aircraft are not successful in their engagement, and the threat continues to close, the surface search radars can be used to help track the target and hand of to the IRST. Either the IRST, or the Digital Array radar can then be used for fire control solutions on the target. When the target closes within

24km, the rail gun can be utilized against the target. If the target is still not neutralized, the FEL, if the vessel is small enough, and the SEA RAM can be utilized against the vessel. If the surface threat should launch missiles, the above air threat sequence would be invoked. The ship has a very robust defensive surface capability and the probability is high that the surface threat will be defeated. Even in the event of a few enemy vessels hiding amid swarms of non-combatant vessels, the FEL can be utilized to successfully defeat the threat.

c. Mine and Undersea Warfare Engagements

These two engagements are similar in the means used to deal with both situations. Ideally, the Sea Force would be kept clear of major mine and undersea threats. The primary mission of the ship is STOM, not hunting mines or submarines. In the real world, however, the Sea Force may find itself involved in an operation when it discovers either a nearby mine or undersea threat. To allow it to safely continue its mission, it has a minimal but highly effective capability against mine and undersea threats. Should the Sea Force become aware of either of these threats, it will attempt to clear the suspected area to a safe distance while minimizing the impact on its current operations. Onboard aircraft and Unmanned Undersea Vehicles will then be deployed to localize and or track the threats. These capabilities can then be used to neutralize the threats or aid other battle group assets in destroying the mine or submarine threats. The Sea Force can then resume normal operations. In the past, ships that were not equipped to handle a mine threat, were forced to leave the area and their operations were effectively stopped until these threats could be neutralized. Technology has enable nearly any ship to retain a mine and undersea capability for a very reasonable cost.

d. Naval Surface Fire Support

The only offensive capability retained on Sea Force was the ability to project fire ashore. While the Joint Strike Fighters will be the primary assets for Marine Close-Air Support, the Rail Gun gives the Sea Force the ability to support more simultaneous fire-support operations. The rail gun, while expensive and power hungry, will provide the capability for the Sea Force to launch both fragmentation and armor piercing projectiles at distance up to 400 NM. The rail gun allows the ship to fire from up to 200NM offshore to 200NM inland. While cost will certainly become an issue for the Rail Gun, it is an excellent weapon that will vastly improve the effectiveness of the Sea Force.

E. PROPULSION/ELECTRICAL

1. Propulsion Plant

The Sea Force is a big ship with 990 ft length, 200 ft beam and with a displacement of about 85 000LT. Several trade-off studies were performed, among them conventional steam plants, diesel engines, fuel cells, nuclear plants and gas turbines. Due to power to weight, power to volume, specific fuel consumption and location flexibility advantages, gas turbines were selected as the prime movers. After resistance calculations for the main and the side hulls, it was seen that we will need a total power of 218 000 HP including 15 MW ship's electrical service load. In order to generate this much power three LM 6000 and one LM 2500+ are utilized.

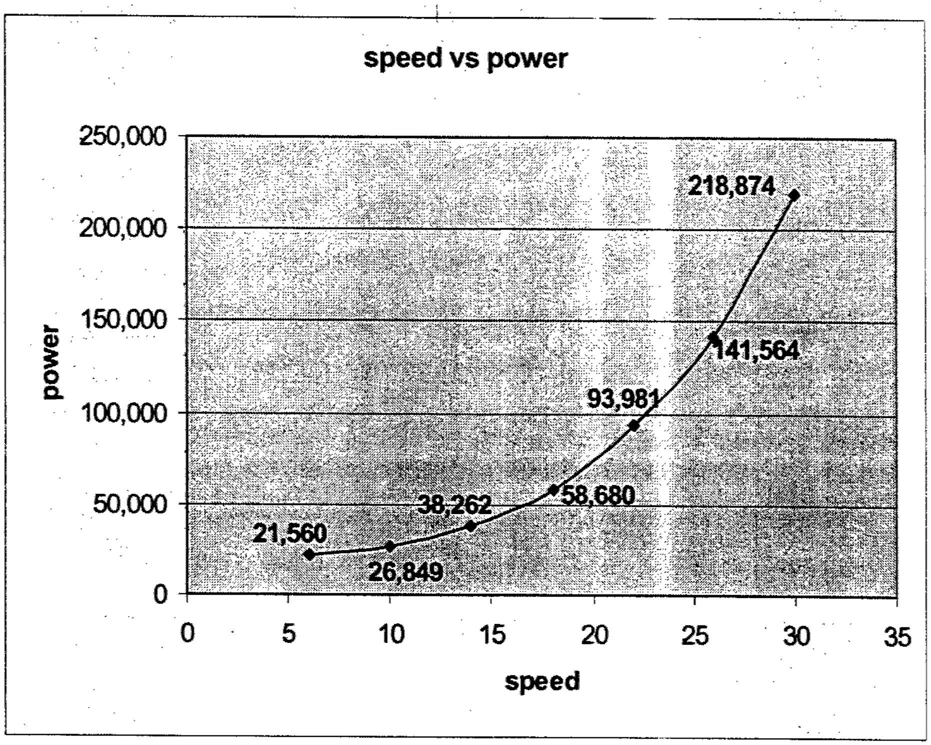


Figure 49. Table 5.1 Speed versus Power Diagram

The LM 6000 gas turbine engines are usually used for the big cargo carrier type ships. This reason was the first starting point for the trade off studies between gas turbine engines. Since volume is an important issue for The Sea Force, along with increased efficiency in SFC, the LM 6000 was selected as the primary prime mover. For the smaller prime mover requirements the LM 2500+ is utilized.

Volume and the weight requirements for The Sea Force were derived based on similar studies on power to volume and power to ratio of the MPF 2010 ship. According to our calculations, the ship propulsion will need a volume of 710,703 cubic feet and 8084 LT weight.

a. Propulsors and Motor Selection

For the propulsors because of the advantages of volume, weight, location flexibility and maneuverability especially at low speeds, pods are chosen.

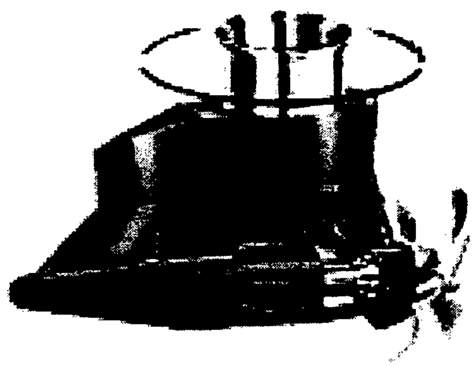


Figure 50. Typical Electrical Pod

One of the main items of concern to the design team, was the dimensions of the pods. Due to the trimaran design, the hull of the SEA Force is relatively narrow. Four pods needed to be installed because of the total power requirement of the ship. In case of two pods; two propulsion motors almost capable of 80MW would be needed. Today's technology doesn't offer that level of power for the propulsion motors. Therefore, the design ended up with four pods.

The other concern for the pods was in terms of size and dimensions. Because of the narrow main hull of the trimaran

design the size of the pods and the propeller diameter were the other problems.

This problem was solved with HTS (High Temperature Superconducting) AC Synchronous Motors. The biggest HTS AC Synchronous motor in terms of power generation is 25 MW, by American Superconducting Company. But today's technology still doesn't give us a good solution. Since the design team was investigating technology that will be utilized by year 2020, it is assumed that 40MW motors will be available at that time with the same dimensions or slightly bigger than today's.

The 25 MW HTS AC Synchronous Motors have diameter of 2.65 and the length of 2.08 meters. Therefore, it was assumed that the pods diameter will be 3.7 meters and the length will be 6.5 meters.

b. Propellers

In order to get the best hydrodynamic efficiency with the 3.7 meters wide pods, calculations for proper diameter of the propellers were conducted for both fixed pitch and controllable pitch propellers. The following graph is offered as a sample of the calculations that were performed.

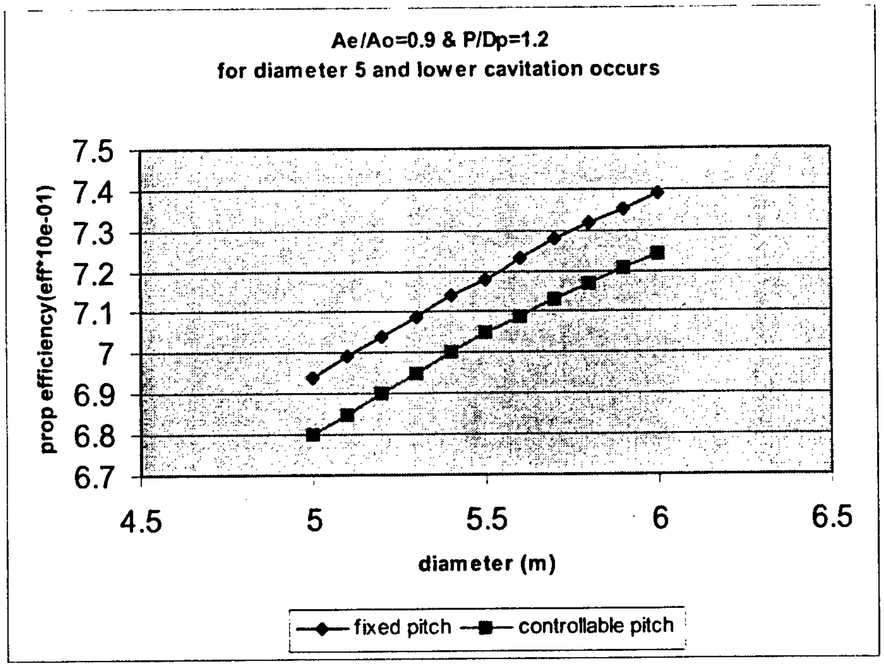


Figure 51. Diameter versus Prop Efficiency Diagram

As can seen from the graph, fixed pitch propellers give better propeller efficiency with smaller diameters. The POP program developed at the University of Michigan was used for our prediction of the propeller design. For all the diameters below 5 m, cavitations occurs.

As a result, a fixed pitch propeller with 5.5 meters diameter was chosen. Since the pods can rotate 360 degrees we don't need to use controllable pitch for maneuvering.

c. *Fuel Calculations*

Two different fuel calculations were made for different speed combinations and speed steps from 5 knots to 30 knots for the range of 10,000 nautical miles.

As seen from Table 21 the LM 2500+ is feasible and efficient in terms of fuel only up to 10 knots. For speeds higher than 10 knots, the LM 6000 starts to offer an advantage.

After these calculations we see that if Sea Force travels 10000 miles with 30 knots it will need about 11,000 LT of fuel. Since it won't necessarily travel at full speed all the time in order to get to the theater, several other calculations were made with different possible speed combinations.

SPEED (KNOTS)	LM 2500+ &ELC LOAD	LM 6000 & ELC. LOAD
5	7546.568058	7677.3254
6	6352.5507	6577.1358
7	5580.3434	5837.8977
8	5001.1468	5343.3305
9	4808.3322	4882.8800
10	4638.5877	4506.7415
11	4342.5846	4329.6252
12	4271.1165	4271.1165
13	4700.5317	4500.0104
14	4343.5297	4209.3195
15	5994.6107	4284.5691
16	5147.3183	4423.2709
17	5203.5545	4556.5517
18	5364.4149	5437.1823
19	5569.8159	5585.2876
20	5899.2950	5750.5733
21	6636.5442	6025.1669
22	6957.051	6369.6684
23	7383.3639	6786.9362
24	7895.6945	7628.7978
25	8144.1889	7590.5269
26	8701.9031	8215.7633
27	9395.1881	8892.3471
28	10274.7802	9585.9682
29	11000.0628	10287.3827
30	11926.6160	10993.8081

Table 21. Fuel Calculation for 10000 miles

As seen from Table 22 combinations of low speed (14 to 17 knots), high speed (27 knots) and loitering speeds for 30 days (5 to 10 knots) were studied. In other words fuel consumption of

transit period for 10,000 miles and 30 days of loitering was calculated. The combination of 14 knots low speed for 90% of the transit time, 27 knots high speed for 10% of the transit time and 5 knots loitering speed for 30 days seems to be the best efficient choice in terms of the fuel consumption with 7394 LT. Similar calculations can be performed for a different speed operational profile for the ship.

SPEED COMBINATION (90% TRANSIT-10%TRANSIT-LOITERING	TOTAL FUEL REQUIRED (LT)
14-27-5	7394.3867
14-27-6	7421.9242
14-27-7	7518.9614
14-27-8	7630.2993
14-27-9	7793.4216
14-27-10	8017.4054
15-27-5	7462.1114
15-27-6	7489.6489
15-27-7	7586.6861
15-28-8	7698.0240
15-27-9	7861.1462
15-27-10	8085.1301
16-27-5	7586.9431
16-27-6	7614.4805
16-27-7	7711.5177
16-27-8	7822.8556
16-27-9	7985.9779
16-27-10	8209.9617
17-27-5	7706.8957
17-27-6	7734.4331
17-27-7	7831.4704
17-27-8	7942.8083
17-27-9	8105.9305
17-27-10	8329.9144

Table 22. Speed Combinations versus Fuel Consumption

d. Engine Room Locations

The Sea Force will have 3 engine rooms. One engine room will be above the waterline and the other two will be below the waterline. The engine room at the aft will include LM 2500+ and one of the LM 6000. The ones below the waterline will enclose the remaining each LM 6000 and auxiliaries. The arrangement of the locations was made due to the volume capacity of the engine rooms. To have one of the engines room above the waterline also increases the survivability.

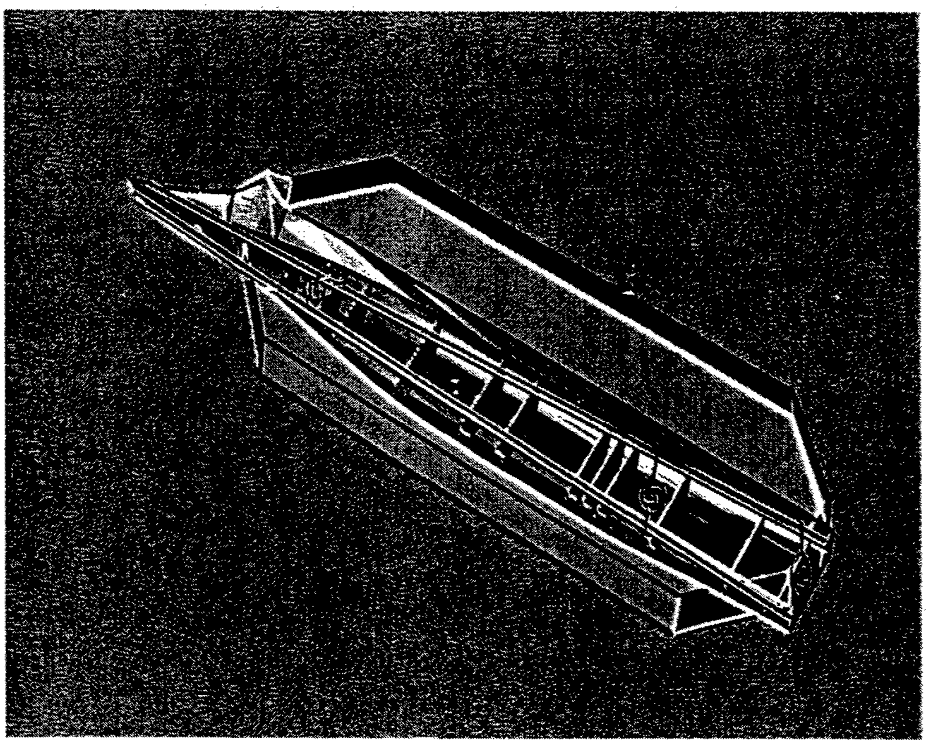


Figure 52. Engine Layout Plan

2. Electrical

The Sea Force electrical distribution system was broken down to four subsystems: power load, power generation, and power distribution and power conversion as discussed below.

a. Power Loads

The load can be broken down to continuous loads and intermittent loads. Continuous loads are the load that may fluctuate with time but always present and includes propulsion, auxiliary and continuous combat system loads

Intermittent loads such as the rail gun and the Free Electron Laser (FEL) are only present during combat operations and place considerable design constraints on the electrical systems. The total installed electrical power was defined as the power to operate the ship at a top speed of 30 knots while at the same time providing the necessary power for ship service loads other than propulsion. Table 23 below shows the required power for major loads

Load	Continuous	Intermittent
Propulsion at 30Knots	144MW	
Propulsion at 20 Knots	40MW	
Ship service electrical load	15MW	
Rail gun + FEL		100 MW

Table 23. Required Power for Major Loads

The total installed electrical power of 159 MW was based on two scenarios:

The first scenario is operating the ship at its top speed of 30 knots, which requires 144 MW, and at the same time being able to operate the ship's service electrical load other than propulsion, which is estimated to be around 15 MW.

The second scenario is to operate combat system at full power, which requires around 100 MW for the Rail Gun and the FEL operations, which limits the ship's speed to 20 knots. Since

the power required for operating the combat system at full power is high and to ensure stable power distribution, the system of flywheels and the capacitors are used to store energy for the combat systems.

b. Power Generation

The total installed power of 159 MW is generated by 3 LM6000 generators providing 43MW each and one LM2500+ generator providing 30MW. Many generators were studied and the selection of the LM6000 and the LM2500+ was based on a trade off study of weight and volume by unit horsepower, the specific fuel consumption and the lowest fuel consumption for the power required. The LM6000 has low specific fuel consumption at high power making it the most efficient under heavy loading. At lower power levels, especially during loitering, the LM2500+ will be used since it will be more efficient. Table 24 below presents the engines specifications:

Engine Type	Output Power (MW)	Weight (kg)	Length (m)	Width (m)	Height (m)	Volume (m^3)
LM2500+	30.11	204117	21.6	4.2	3.6	326.592
LM6000	43	259863	17.2	4.1	4.4	310.288

Type	Number of Engines	Power (MW)	Weight (T)	Volume (m3)
LM6000	3	129	779589	930.864
Lm2500+	1	30.11	204117	326.592
	Total	159.11	983706	1257.456

Table 24. Generators' Specifications

For survivability reasons one LM600 and one LM2500+ will be located in the Main Engine Room One (MER1) in zone one, one LM6000 will be located in the MER2 in zone 4 and the last

LM6000 will be located in the MER3 in zone 12. The four generators will be connected to each of the four buses through the appropriate breakers.

One LM2500+ can provide the 15MW for ship service and the power required for propulsion to a speed of up to 14.5 Knots, which is perfect for loitering and cruising at low speed. If more speed is needed or high power is required for combat system we can operate the other gas turbines. Table 25 below shows the total speed that can be achieved using different gas turbines.

Gas Turbine	Ship's Service Electric Power	Prop Power (MW)	BHP	Max Speed (knots)
1Lm2500+	15MW	15	20115.32788	14.5
1Lm6000	15MW	28	37548.61204	18
1Lm2500+an d 1LM6000	15MW	58	77779.2678	22.5
2Lm6000	15MW	71	95212.55196	23.5
1Lm2500+2L m60000	15MW	101	135443.2077	26.5
3LM6000	15MW	114	152876.4919	27.5
3Lm6000 +1Lm2500+	15MW	144	193107.1476	30

Table 25. Speed and Engine Combinations

c. Power Distribution

For the electrical distribution integrated power system architecture was chosen. A combination of AC and DC zonal electrical distribution system (ZEDS) was used. Although DC ZEDS has many advantages over the conventional AC we couldn't limit our distribution system to DC only because at this high power all the electrical propulsion motors are AC due to commutation limitations in DC motors that limit their applications in our podded propulsion. More importantly, the power electronics available for a DC system are expensive and limited in voltage. The mechanical switchgear for DC equipment is both limited in current and high in cost, adding to that distribution and

protection coordination issues associated with an all DC system leads to a hybrid system being favored for this application.

Four buses will cross the ship, two buses on the port side and two on the starboard side, with two buses above the waterline and two below the waterline. Two of them will carry 4160 VAC and the other two will carry 1100 VDC.

For survivability reasons, the four buses will be tied to each of the four generators. This architecture will allow the ship to be sectioned into multiple zones that are powered from the port or starboard AC and DC bus ties. This will minimize the number of electrical penetrations through the watertight bulkheads and allowing for modular construction and testing.

The ship is divided into 15 zones corresponding to the ship's 15 watertight bulkheads. In each zone a combination of AC and DC ZEDS is used. The AC buses are connected to the zone through a step down transformer and the DC buses are connected to the zone through SSCM and diode auctioneering giving an output of 900 VDC for the port side and 850 VDC in starboard. Through diode auctioneering, if primary 900 VDC power source is lost the secondary 850 VDC power source will be ready for back up to provide power for the vital loads.

The sensitive port AC and DC equipment requiring a smooth waveform are connected to the port DC bus through a SSCM and a SSIM and the sensitive starboard AC and DC equipment are connected to the starboard DC bus through a SSCM and a SSIM. The sensitive vital loads such as combat system computers or lighting are tied to both buses.

The non-sensitive equipments that do not require a smooth waveform are connected to the AC buses through a step down transformers and SSCM. Figure 53 shows a typical in zone electrical distribution

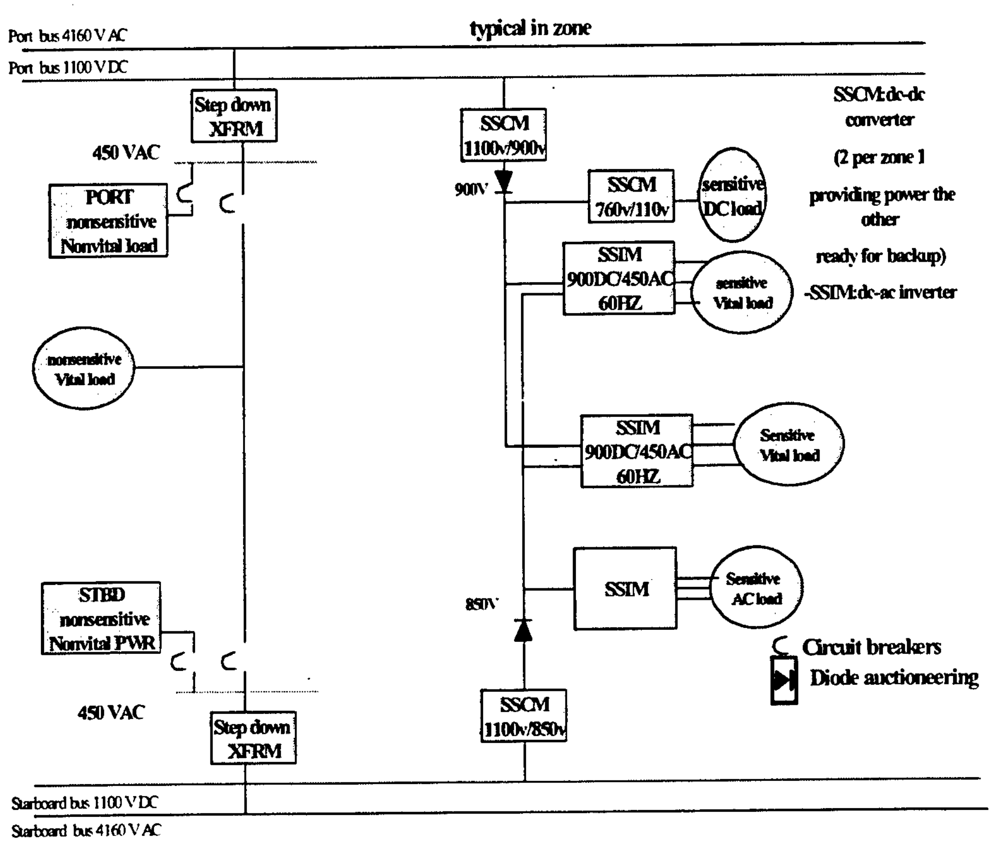


Figure 53. Typical in Zone Electrical Distribution

The generators are located in the three engine rooms. Two of them are in the first zone the third zones, and one is in the fourth zone and the last one in the zone 12. The propulsion motors are tied to both AC buses thought propulsion motor

modulus, which consists of a transformer and a cycloconvertor. The FEL and real gun are also tied to both AC buses. Figure 54 shows the generators locations, their connection to buses and the propulsion motors connections to the buses.

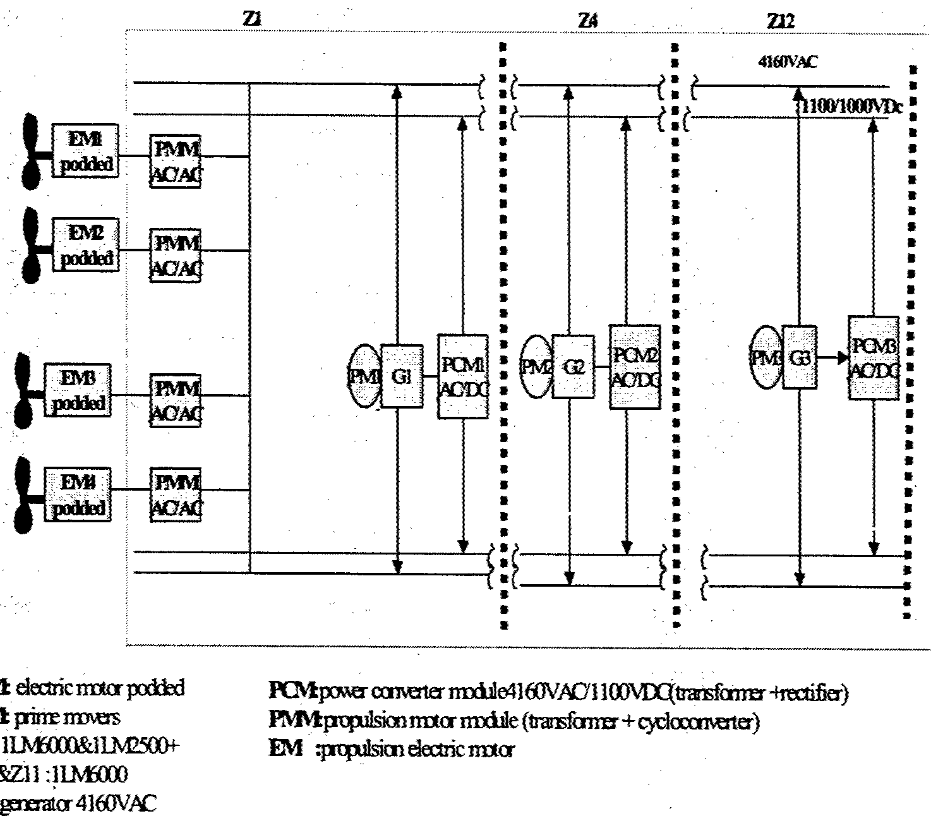


Figure 54. Generator Locations and Connections

d. Power Conversion

The four major power conversion modules used are: propulsion motor module PMM and power conversion module PCM-1, PCM-2 and PCM-4 and are described below. These power modulus are the main factor in limiting the DC bus power to 1100 V because

of the use of insulated gate bipolar transistor power semiconductor devices that are limited in voltage.

Power Motor module PMM

PMM is basically transformer and cycloconvertor use to convert the 4160 VAC, 3phase, 60 Hz power provided by the 2 AC buses to the appropriate variable voltage and frequency required by the 4 40 MW HTS superconducting propulsion motors required for the podded propulsion. We will need four PMM modules one for each propulsion motor. The unit weight and volume is approximated to be 45.15 mT and 26.78 m^3.

AC-DC Power Conversion Module PCM-4

The PCM-4 is used to convert the 4160 V AC to 1100 V DC through a step down transformer and is then fed to the two DC buses. Four PCM-4 modules are used in the ship one for each generator. The four of them will be located in the engine rooms and are tied to each of the two DC buses. The weight and volume of each unit is approximated to be 69.4 mT and 66.9m^3

DC-DC Power Conversion Module (PCM-1)

This module is also called the ship service converter module (SSCM). The purpose of the SSCM is to provide a buffer between the main 1100 V DC bus and the inter-zonal loads and to lower the main DC bus voltage from 1100 to a regulated level commensurate with DC to AC inverter input requirement which is about 900/ 850V. Each zone will have two SSCM one will give an output of 900v and the other an output of 850V. The total for our ship will be 30 unit at an estimated unit weight and volume of 2.51mT and 4.44. SSCM will also be used to convert the 900

VDC coming from the buses to a lower voltage required by the electrical equipments.

DC-AC Power Conversion Module (PCM-2)

This module is also called the Ship Service Inverter module (SSIM). The SSIM are used to convert the 900VDC to a regulated variable voltage, variable current and variable frequency stable wave form AC current to supply the sensitive electrical loads inside the zone. The number of SSIM in each zone will be at least two based on the different voltages and frequency required. The weight and volume of the SSIM per unit is estimated to be 7.71 mT and 11.93 m^3.

A summary of the weight and volumes for the generators power electronics is tabulated below.

Type	LM6000	LM2500+	PCM-4	PCM-1	PCM-2	PMM-1
Function	Gen	Gen	AC/DC	DC/DC	DC/AC	AC/AC
Weight (MT/unit) Year 2012	220.88	173.50	69.40	2.51	7.71	45.14
Volume (m^3) Year 2012	263.74	277.61	66.10	4.44	11.93	26.78
Number of Units/zone	1	1	1	2	1	1
Number of Zones	3	1	4	15	15	4
Total Weight (MT) Year 2012	662.65	173.50	277.60	75.18	115.67	180.54
Total Volume (m^3) Year 2012	791.23	277.61	264.38	133.16	179.01	107.10

Table 26. Distribution System weight and Volume Breakdown

F. DAMAGE CONTROL

Mission accomplishment while operating in harsh environments is the raison d'etre of a warship. One of the most distinctive factors that measure the mission performance capability of a warship is the survivability of the ship. Traditionally, the damage control readiness of current warship utilizes suppression systems which have limited use of automation, remote sensing technologies, this lead to systems that are highly manpower oriented and dependant on the training and experience of the ship's damage control parties. The damage control systems are not deliberately designed for pre-emptive action thus ensuing delays due to manual suppression systems take time and the value of time in damage control can lead to catastrophic or life saving repercussions on mission accomplishments and the survival of the ship

In a reduced manning oriented Sea Base ship design, the importance of maintaining optimal damage condition readiness where manpower is a constraint that becomes even more important. Ensuring that an optimally manned warship is still able to meet the damage control readiness standards imposed; necessitates the exploitation of technology supplemented by damage control concepts such as DC-ARM.

1. Goals

The main goals of the damage control (DC) system architecture onboard the Sea Base ships are:

a. Sensing

- Maintain real-time situational awareness of the overall systemic environmental and structural health status of the ship and crew.
- Increase sensitivity and decrease detection time to allow pre-emptive prediction and real time assessment.
- Increase reliability by decreasing nuisance alarms.
- Automation and rapid recovery in damage control.
- Ability to provide reconfiguration of systems in response to casualties.

b. Operations and Recovery

- Operate pumps and valves remotely and automatically.
- Isolate ruptures without human intervention or network communication.
- Withstand multiple failures and component degradation.

2. Main Systems

The sea based ship will embrace the existing cutting edge damage technology fitted onboard the LPD 17 as well as facilitate the implementation of future technologies currently under exploration. To ensure damage control readiness and rapid recovery, Sea Force exploits automated technology in the areas of sensors, valve and pump operations, rupture isolation, component redundancy and system reconfiguration in response to casualties.

Many of these functions are accomplished through real-time sensing using the Ship Wide Area Network (SWAN). Additionally, a water based blast mitigation system providing pre-emptive

response capability is embedded into the SWAN to permit corrective DC actions in areas of expected damage from impending missile hits or other attacks. The central nerve system of the damage control automation resides in the Supervisory Control System, which serves backbone for Sea Force's damage control architecture. The following is a summary of the main systems on board the Sea Force:

- An intelligent and distributed control system- that integrates overall damage control functions and maintains adequate systemic redundancy through multiple distributions throughout the ship.
- Early Warning Fire Detection (EWFD) system- wide array sensors that are distributed through out the ship to provide early detection and warning of potential fire conditions and reduce the false alarm rate
- An area-wide water mist fire protection system- provides the sea base ship with fire suppression system that also functions as an automated boundary cooling system in the primary fire compartment.
- Comprehensive ventilation system- Based on the experimentation conducted on USS Shadwell, the Sea Force will have a collective protection system (CPS) and a smoke ejection system (SES) that is integrated of ductwork, automatic dampers and actuators to remove smoke from selected shipboard passageways [48].
- Autonomous smart valves - that enable rapid detection and isolation of damaged fluid systems
- Wire Free Communication (WIFCOM) capability that is able to integrate into the ship's main damage control network and allow intra compartment network communications. It will

provide unobtrusive effective communications between the damage control teams and DC central stations that are essential for conducting efficient DC operations.

- Similar to last year TSSE Sea Archer design, a personnel electronic tagging device will be implemented to assist tracking of all personnel onboard the ship.

The Sea Water and AFFF systems are distributed longitudinally in the machinery spaces. These are served from a vertical offset loop fire main system as shown in the Figure 55 below. An extensive sprinkling arrangement in the berthing, storerooms, magazines, and selected vital spaces is incorporated to provide protection for personnel and control the spread of fire. Two redundant water mist systems (port and starboard) feed a centerline main that distributes an atomized mist of water to extinguish fires and protect the main and auxiliary machinery spaces. Six independent AFFF stations serve firefighting sprinkling systems and hose stations in the magazine, well deck, vehicle decks, flight deck and all main and auxiliary machinery spaces. A tabulated description of the main fire fighting equipment employed is included in Table 31. An optimal separation of redundant vital systems such as the vertical offset loop - Firemain and Chill Water system, the zonal 60 Hz power distribution system, and the distributed SWAN servers.

Compartment	FM 200	CO_2	Water Mist	AFFF
Machinery spaces	--	--	X	X
Engine enclosures	--	X	--	--
Magazine areas	--	--	--	X
Electronics equipment rooms	X	--	--	--
Hangar	--	--	X	X
Vehicle Deck			X	X
Well Deck				X
Flight deck	--	--	--	X
CIC	X	--	--	--
Bridge	X	--	--	--
Accommodations	X	--	--	--
Kitchens & Galley	X	--	--	--
Offices	X	--	--	--
Passageways	X	--	--	--
Paint lockers	--	X	--	--
Pump rooms	--	X	--	--

Table 27. Table 1: A summary of the main damage control systems and their employment onboard.

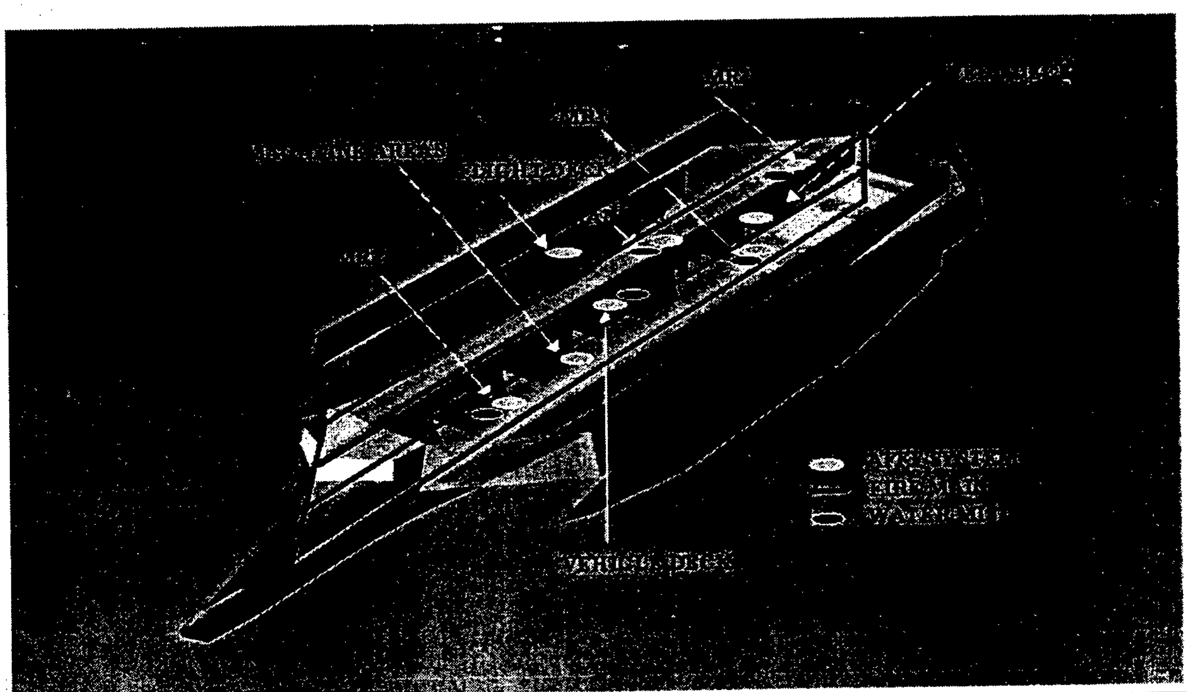
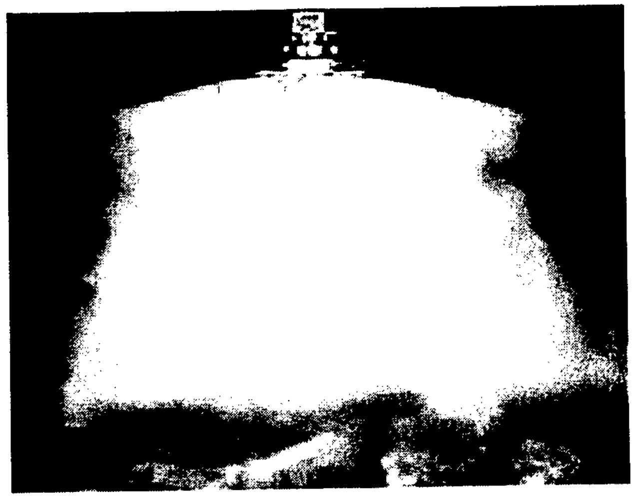


Figure 55. Depicting the Sea Force's AFFF distribution and fire main distribution.

1. Water Mist Systems

During last ten years, improvement of this technology made it preferable for the fire fighting systems. After the halon gas was banned by the most countries in the world water mist took its place. The fire is made up of three main principal constituents, which are flammable material, heat and oxygen. Water mist system eliminates two of the three factors; heat and oxygen.

The mist created by the systems consists of small drops of water measuring 5-200 μm. The atomized water droplets are drawn to the base and expand in volume by 1700 times to replace the oxygen. These are sprayed into the fire area where the mist is transformed into vapor - a process that consumes great amounts of energy and thereby reduces the heat produced by the fire. The heat reduction occurs more than 100 times faster than when normal sprinklers/nozzles are used, even though these use as much as 20 times more water. To supply the small drops of water and at the same time ensure adequate throw needs a minimum pressure of 80 bars.



It cools the fire area in a very short time. This allows firefighters to enter the fire area and extinguish fire. Because of its cooling effect and room flooding ability, water mist systems prevent reigniting. Major advantages of this system are significant savings on weight & space requirements. Easy installation due to small pipe dimensions, minimal damage because of the amount of water used, quick cooling down, harmlessness to people and environment, high durability, ability to be combined with other remote releases.

Besides advantages, the system has disadvantages like every system does. It doesn't do well for small fires. Even the cost of the system decreases day by day, these systems tend to be somewhat more complicated and more expensive than the conventional sprinkler systems. Typically requires greater water pressure than conventional sprinklers. While some water mist systems have been developed to operate at relatively low water pressure, most water mist systems require compressed gas or high-pressure pumps to create the atomized spray necessary for proper operation.

The sea base ship will have a port and starboard systems that provides redundancy. Either system will be able to feed the centerline main. This will distributes an atomized mist of water

to the following compartment to extinguish fires and protect the main and auxiliary machinery places.

2. Water-Based Blast Mitigation

One concept currently under development in ONR is the "water-based blast mitigation program to determine the efficacy of fine water droplets to reduce the propagation speeds and quasi-static gas pressure buildup following a weapon explosion."[1]. A water based mitigation system essentially sprays atomized water droplets into the compartment similar to the water mist systems above, however instead of being deployed as a preventive system it is integrated into the shipboard SWAN LAN. Based on current ONR research the atomized droplets serve to minimize the blast effect of the impending detonation by

- *absorbing the pressure energy in the blast wave (energy "stripping")*
- *quenching the flame front and fireball*
- *partial absorption of the heat of detonation*
- *reducing the likelihood of post-blast ignition of combustibles and*
- *subsequent fire spread* [2]

For the Sea based trimaran hull form, the side hulls are currently design to carry seawater ballast tanks and acts as innate static protection buffer against damage to the main hull. There is no loss of buoyancy if the side hulls are damage since they were originally filled with seawater. With the water-based blast mitigation system, locations in the main hull that are unprotected from the side hulls can have further protection.

3. Distributed Control Architecture

The use of an intelligent and robust damage control architecture distributed throughout the ships will be a critical enabler. It will serve to bind the entire damage control architecture together into an efficient system that enhances survivability and aids mission accomplishment. The Sea Force will adopt the DC-ARM Supervisory Control System(SCS) approach. The SCS is primarily "a hierarchical distributed control system that provides a user interface for displaying DC sensor information, pre-hit damage prediction, video, door closure, automated decision aids and automatic actuation of DC systems." [47]

The SCS will be integrated into the shipboard SWAN and provide a collated and fused knowledge of the overall operating environment/condition onboard the ship. A list of the basic functions garnered from reference [47] is appended below:

- Control the fire main and automatic valves.
- Controls the water mist system.
- Provides fire alarm and fire characterization information.
- Provides video surveillance of compartments.
- Provides access closure information.
- Provides for the entry of information from verbal reports.
- Provides a simulated combat system interface with threat status information.
- Provides the ability to define operational priorities that would influence DC priorities.
- Provides displays to characterize damage.

- Provides decision aids to assist with managing the DC response.

There main DC control station is in the aft MER, located below the waterline in the main hull and longitudinally positioned between the side hulls. Two other smaller subsidiary DC control sub-stations will be positioned in the forward MER and the aft_01 MER. Separated longitudinally and transversely on the ship, they provide multi-layered redundancy capability and ensure a high level of damage control readiness in all eventualities. Each control station will have the ability to override and/or supplement each other in the event of damage or failure. As the shipboard LAN provides the medium for the exchange of damage control data, critical locations such as CIC and bridge will have workstations that are able to monitor and draw on the information generated by the SCS.

Future growth capabilities will include the ability to fused external threat environment data derived from shipboard sensors and CEC and integrate them into the inboard damage control readiness. This will allow the Sea Force to have pre-emptive capabilities in damage control. Concepts such as water based mitigation using atomized water mist systems can then be incorporated as an active anticipatory damage control system that gives the ship a "flinch" capability in anticipation of imminent damage to a particular compartment.

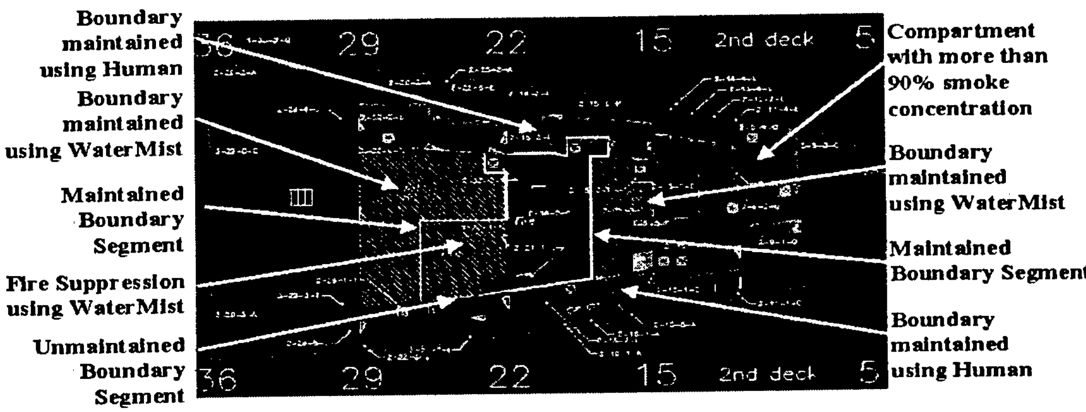


Figure 56. Typical SCS Compartment Damage Display (Source reference [47])

3. Reduction in Manning

During normal cruising stations, only the main DC station will be manned while in Condition Zebra, all three control stations will be manned to maintain the highest level of readiness. The DC-ARM experiments onboard the USS Shadwell advocates 30% of the crew to be allocated for the DC organization structure [49]. Extrapolating to the Sea Force, a DC-Arm organization consisting of 12 man team performing the daily monitoring via the SCS system and supplemented by ready damage control teams of 220 active shipboard personnel will be sufficient. The figure below is taken from a demonstration on the SCS architecture by ONR, it is a characteristic representation of the optimally manned damage control station and serves to reinforce the damage control concept embrace by the Sea Force.

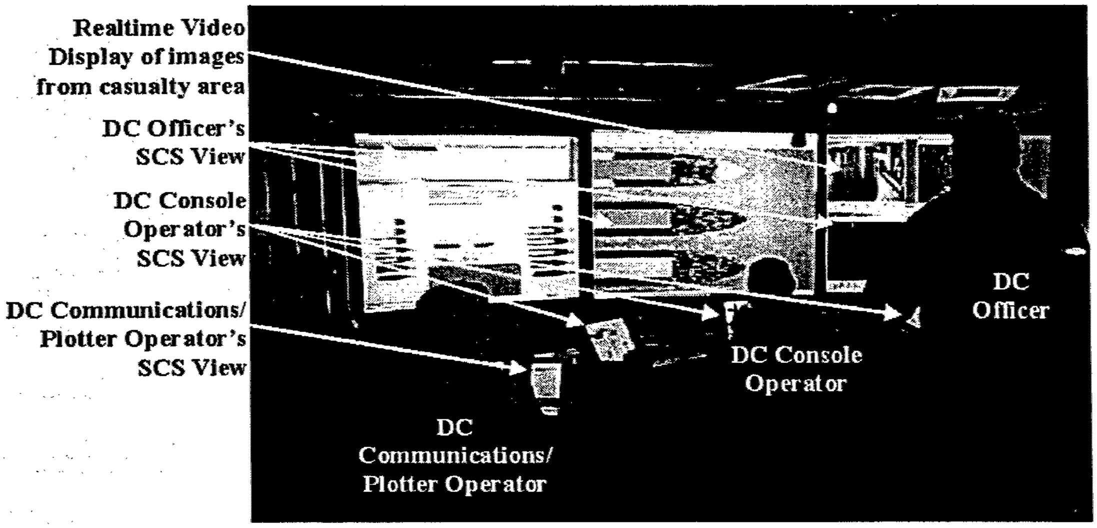


Figure 57. DC Central Photo from FY01 Demonstration (Source reference [47])

3. CBR Measures

The team decided in the early design phase that it will be unfeasible and exorbitantly expensive to design the sea base ship to retain the full spectrum of operational capabilities if it was to operate in a CBR environment. However, the design will have nominal CBR facilities to allow the ship to conduct reduced frequency air and surface operations in a CBR environment. The main CBR capabilities include:

a. Air operations

Sea Force will have collective Protection system in Aircraft Elevators similar to last year's TSSE design. Both aft aircraft elevators will have a collection protection system and act as decontamination areas. Reduced flight operations can be sustained in a CBR environment.

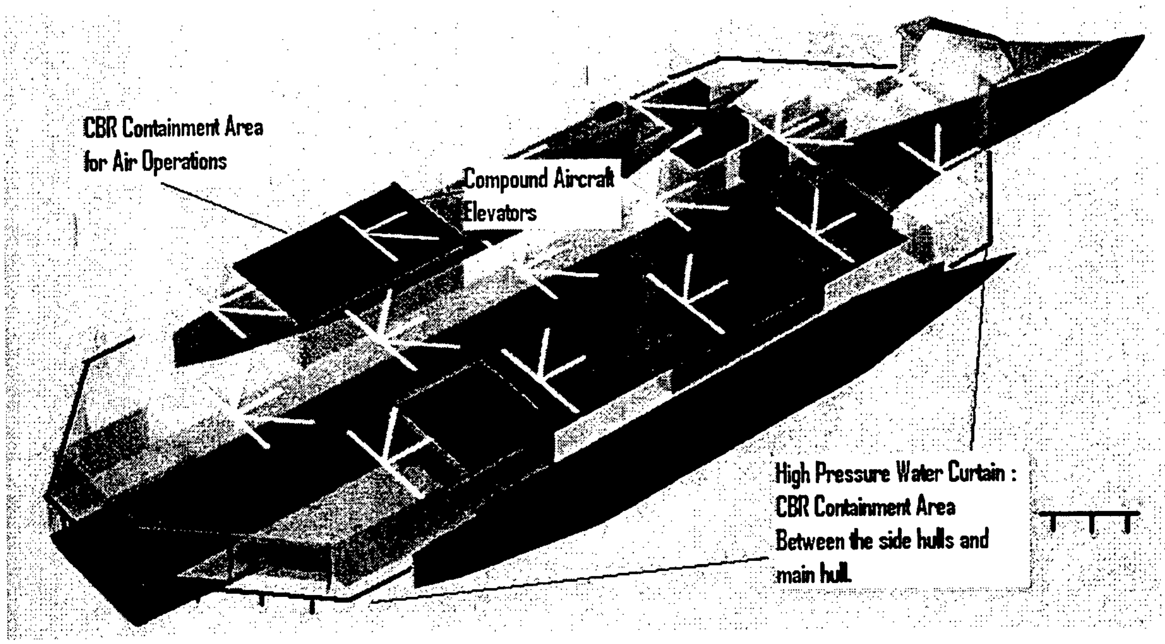


Figure 58. CBR Boundaries

b. Surface Operations

The area between the side hulls and main hull serve as ideal locations to implement a CBR containment area for surface LCU operations. Sprinklers will be located transversely forward and aft along the mid body connecting the side hull and main hull to form water curtains. The water curtains will form a continuous water shield to provide a simple and effective "safe" area. A total of four LCUs can operate in the safe area between the side hulls; however the ship will be constraint to almost stationary profile when the LCUs are between the side hulls. A similar system will be in placed at the transom end of the well deck.

4. CONCLUSION

The expanded use of technology and the integration of damage control readiness as a total system design of the ship

from the onset, ensures that the sea base ship is highly survival and responsive to the ever changing threats thrust upon the ship. By reducing the vulnerability of the ship to damage or failures cause by intra or external factors, the ship will have improved and sustained warfighting capabilities while optimally manned.

G. LOGISTICS SYSTEMS

One of the greatest challenges for expeditionary operations is logistic support. More than likely, the nature of future expeditionary operations does not appear to reduce the logistic requirements. On the contrary, Expeditionary Maneuver Warfare (EMW) relies on both, agility at sea (OMFT), and on the ground (STOM). EMW introduces two different logistic challenges. The need for swift maneuver and reconstitution of forces requires rapid and precise delivery of supplies. The reduction of the footprint ashore also decreases the need to protect supply lines making our forces leaner and maneuverable.

The second challenge is indefinite sustainment. Currently, the Marine Corps relies on three Maritime Prepositions Squadrons (MPS), which provide equipment and supplies for 30 days. Each MPS is composed of 4 to 6 ships with no combat systems or self-defense capability. The ships require port facilities or a suitable location, and approximately 10 days to off load. The ships do not have selective on load or off load capabilities, meaning that the force might end up protecting supplies and equipment that are not required for a particular mission.

The solution to the indefinite sustainment problem is to transfer all the tasks associated with this mission to Sea Base ships. These ships will have the capability to interface with

Military Sealift Command (MSC) and commercial shipping. Selective on load and off load will allow them to take and transfer only the required equipment and supplies. The Sea Base ships will be a supply warehouse and a distribution hub, providing the forces ashore not only with supplies, but with other essential services such as maintenance for equipment and medical care for casualties. In summary, now more than ever, logistic support through Sea Basing will play an extremely important role in EMW, and the success of future operations will directly depend on how well we can adapt our current doctrines, how well we can implement new methods, and technology for logistic support.

1. Requirements

The logistic support requirements for the TSSE concept design were based on the sustainment requirements for a Marine Expeditionary Brigade (MEB) found on CDR Kennedy's thesis [3]. Table 28 illustrates the daily requirements for provisions, ordnance, and fuel. Two supply rates, standard and surge are illustrated in the table. Surge rate was used to calculate the total weight and volume for a 30-day period. Table 29 illustrates the final sustainment number for all commodities per ship.

Commodity	Days	Std. Rate (ST/Day)	Weight	Volume (ft^3)	Surge Rate (ST/Day)	Weight	Volume (ft^3)
Provisions	30	95	2850	304000	95	2850	304000
Ordnance	30	550	16500	880000	687. 5	20625	1100000
Total			19350	1184000		23475	1404000

Table 28. Daily Sustainment Rates, Weight, and Volume for a MEB (Source reference [3])

Commodity	Weight per Ship (ST)	Volume per Ship (ft^3)
Provisions	475	51200
Ordnance	3438	184320
Total	3913	235520

Table 29. Weights and Volumes for 30 Days Sustainment per Ship

a. Provisions and Ordnance Requirements

To calculate the number of containers of provisions and ordnance we also took CDR Kennedy's approximation that a 20'x 8'x 8' standard container (TEU) loaded with provision weights approximately 12 tons, and that a TEU loaded with ordnance weights approximately 24 tons. To obtain the total number of TEUs the weight for provisions was divided by 12, and the weight for ordnance was divided by 24. The number of TEU loaded with provision and ordnance was calculated to be approximately 40 and 144 respectively. In addition, it was assumed that each TEU is loaded with 20 pallets. The number of provision and ordnance pallets was determined to be 800 and 2880 respectively. Table 30 summarizes the number of TEU, pallets, or a combination of both, required to be in stock per Concept Design to sustain a MEB for 30 days.

Commodity	TEUs	Pallets per ship	Total Pallets MEB
Provisions	40	800	4800
Ordnance	144	2880	17280

Table 30. Number of Pallets for 30 Days of Sustainment per Ship

b. Transfer Rate Requirement

To obtain the number of containers required in a day to replenish the supplies transferred ashore, the number of provision and ordnance containers was divided by 30. The approximate number of provision and ordnance containers needed to be transfer per day to the Sea Base ships was 2 provision and 5 ordnance containers. Because ships of the Sea Base must sustain not only marines ashore, but their own crew, the required transfer rate was set to 15 TEUs a day.

c. Fuel Requirements

The required amount of fuel for the Ground Combat Element (GCE) to be carried by the Sea Base ships was taken from the Center for Naval Analysis (CNA) study *Fuel Requirements and Alternative Distribution Approaches in an Expeditionary Environment*. CNA determine that the amount of fuel required daily to sustain a MEB ashore was approximately 80,000 gallons [50]. This quantity was multiplied by 30 to determine the amount of fuel required for 30 days. The amount of fuel required to be carried by each ship for 30 days sustainment was determine by dividing the 30 day sustainment figure among the 6 ships. Table 34 summarizes fuel requirement needed to be carried by each ship.

Gallons/ Day	30 Day Sustainment	Fuel Required per Ship	Fuel Required per Ship in ST
80,000	2,400,000	400,000	1,360

Table 31. Fuel Requirements for 30 Days of Sustainment per Ship (GCE)

The required amount of fuel for the Aviation Combat Element (ACE), LCACs, and LCUs to be carried by the Sea Base ships was calculated using the burn rate for each type of craft, the number of sorties required for both standard and surge sustainment rates, and assuming 250 nautical mile range (nm) from the Sea Base to the objective for aircraft, and 50 nm from the Sea Base to the beach for watercraft. Table 35 summarizes the fuel consumption for all aircraft, LCACs, and LCUs, and the amount of fuel required to be carried by the Sea Forece.

			Surge Rate	Standard Rate			Surge Rate	Standard Rate
	# per ship	Burn rate (lb/hr)	# Sorties per day	# Sorties per day	Range (nm)	Speed (knots)	Fuel (gallons)	Fuel (gallons)
QTR	4	4,000	4.0	2.5	500	200	29,412	18,382
AH-1Z	4	800	3.0	3.0	650	152	6,037	6,037
UH-1Y	4	800	3.0	3.0	650	120	7,647	7,647
MV-22	16	350	4.0	2.5	500	240	6,005	3,753
JSF	6	2,000	3.0	3.0	500	875	6,618	6,618
							55,719	**42,437**
		(gal/mile)						
LCAC	3	16	9.0	2.0	50	35	14,400	3,200
LCU-R	2	0.86	4.0	1.0	50	15	344	86
							14,744	**3,286**
Total Fuel for 30 Day Sustainment							**2,103,300**	**1,371,690**

Table 32. Fuel Requirements for 30 Days of Sustainment per Ship (ACE,LCAC,LCU)

2. Systems Description

Following the requirements analysis, exploration of possible solutions took place. The transfer and logistics systems had to be able to transfer and handle containerized, palletized and liquid supplies. The Sea Force has to be capable of interfacing with MSC and commercial shipping. The system has to be capable of selective on load and off load and interface as smoothly as possible with well deck and flight deck systems in order to facilitate the distribution of supplies to the forces ashore. All these tasks had to be satisfied while at the same time, considering reduces manning through automation, and minimum interference with other systems.

The Sea Force trimaran hull form with its triple tram line allows for optimal logistics distribution via aerial means via the flight deck. An illustration of the inter ship and intra ship material handling modes are depicted in figure 59 and 60 respectively. In order to maximize throughput and facilitate indefinite sustaintment, the primary modes for logistics transfer will be via VertRep and SurfRep

a. Primary

- Vertical Replenishment (VERTREP): There are 16 aircraft spots for airborne assets such as MV-22 and heavy lift helicopters to handle up to pallet size loads.

- Surface Replenishment (SURFREP): There are two well deck spots and LCU ramp access between the hulls to support Surface Replenishment of larger TEUs and quadcon size loads using LCACs & LCUs.

- The Hybrid Linear Electric Drive system provides rapid intra-ship mobility of cargo loads up to 12,000 lbs.

b. Secondary

- Motion Compensated Cranes to provide Lift-On/Lift-Off capability for containerized TEU cargo.

- Connected Replenishment via high lines (CONREP) to provide up to 12,000lb.

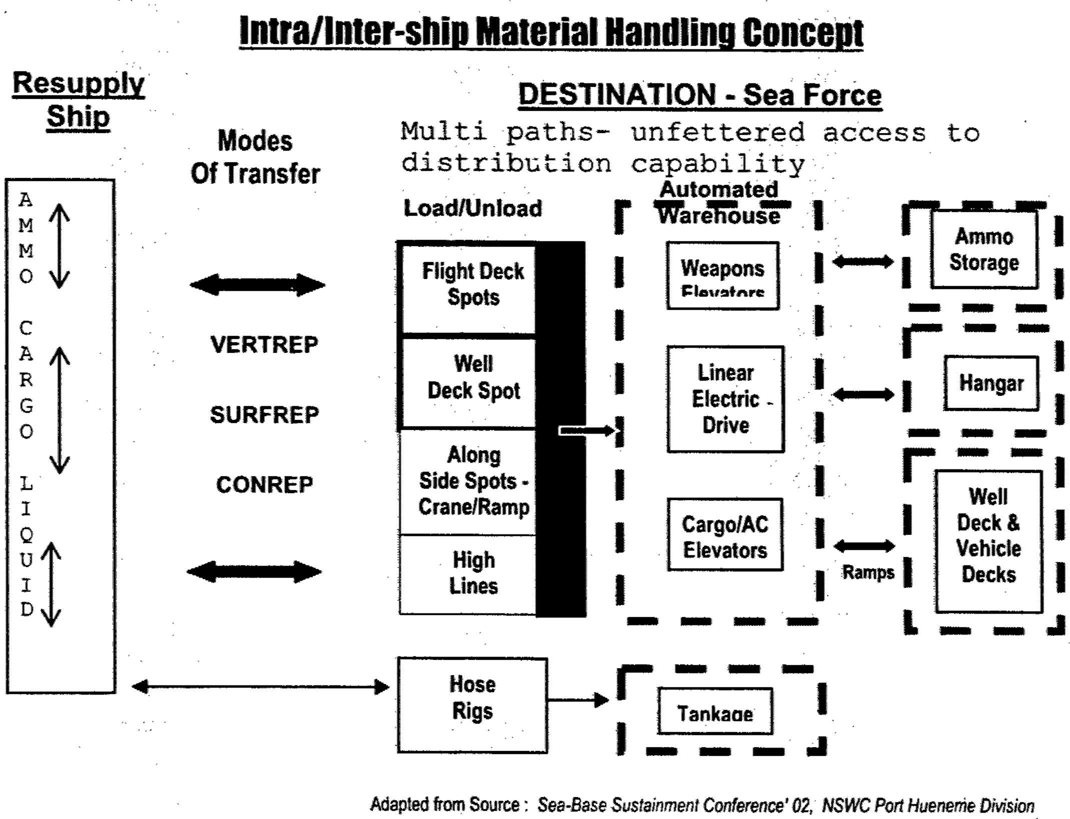


Figure 59. Schematic of the Inter/Intra ship Material Handling Concept on Sea Force.

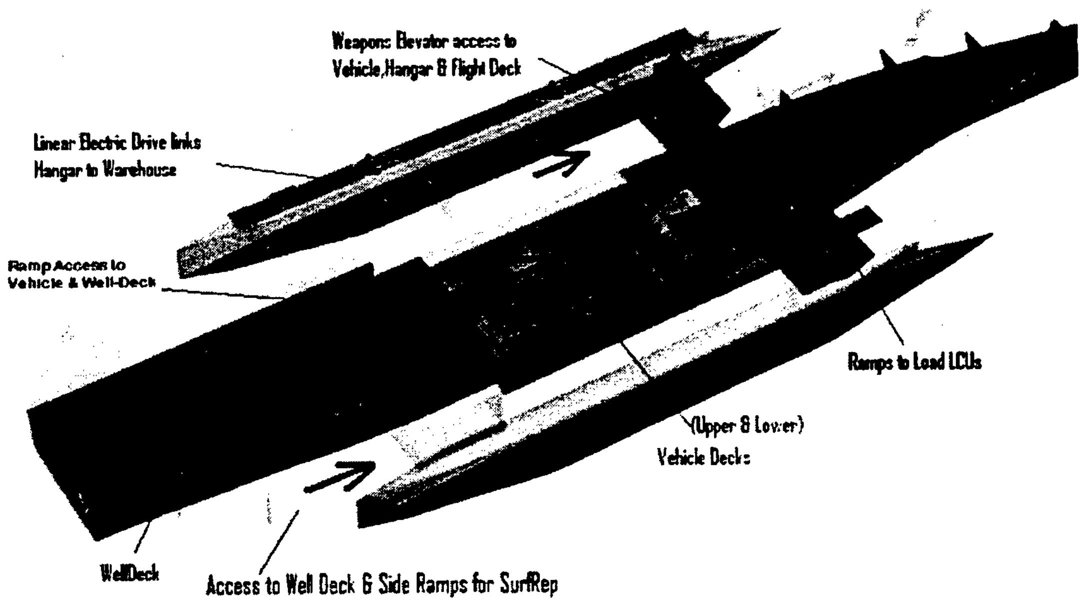


Figure 60. Intra Ship Cargo Handling Sea Transfer Systems and Interfaces

Although the need for ship to ship transfers is minimize in the Sea Force operational concept as the primary means for inter ship transfer from the sea based ship to forces ashore (or vice versa) is through VertRep via air borne assets. It is envisaged that to function effectively as the logistics distribution and provide indefinite sustaintment, the ship will need to retain the capability to conduct strategic logistic interface with commercial compatible sea base replenishment platforms or legacy support ships from CONUS.

Several systems were considered in order to maximize throughput and redundancy the ship, and it was determined that the design should preserve the ability to conduct Connected Replenishment using high lines (CONREP) or via the ship's motion compensated crane which is integrated into the warehouse. The Handling of liquid cargo will be via dedicated the two refueling positions located on both port and starboard sides of the ship. The following paragraphs describe in more detail each one of the transfer and storage systems used in the Sea Force. Figure 59 illustrates a schematic of the different methods used to transfer cargo to and from the Sea Force and Figure 60 illustrates the different intra ship transfer methods to enhance the efficiency of material handling within the ship.

c. Hybrid Linear Induction Drive

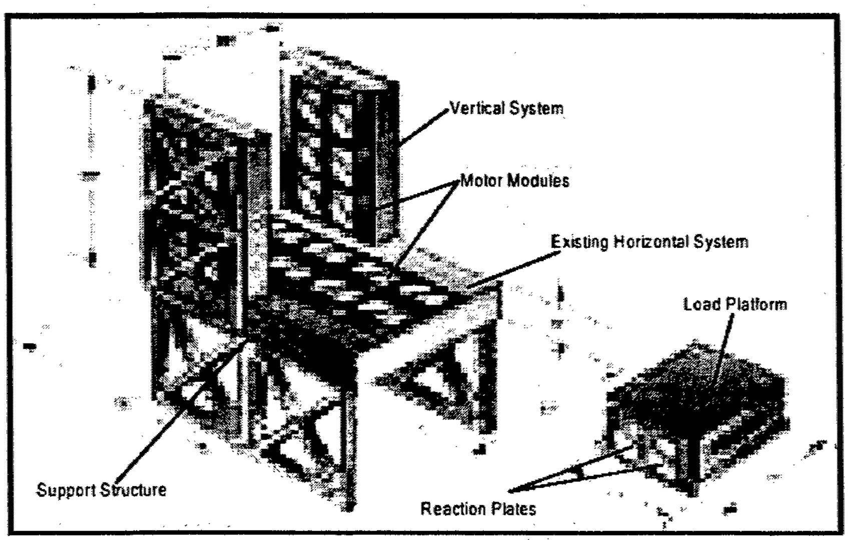


Figure 61. Hybrid Linear Electric Drive

The Hybrid Linear Electric drive currently under research in ONR has the capacity to handle up to 12,000 lbs weight and provides significant improvements in cargo movement. It is

mounted along the port side of the main hull and improves integration ability since it adheres to the contour of the hull and optimizes the available space for other usage. In the Sea Force design, the Linear Electric drive system will provide rapid access through the hangar bay to the LCU ports and aircraft elevators for loading and unloading. Based on ONR's projection, increased throughput speed, up to 30 % workload reduction; 20 % weight reduction and 20 % power consumption reduction over current systems are potential benefits that can be accrued with the use of the Linear Electric Drive system because of the ability to handle larger loads and in reducing the workload due to robotics & automation.

d. Motion Compensated Crane System

A prototype of a motion compensated crane for the Mobile Offshore Base (MOB) has been developed by Scandia National Laboratory and Carderock.[3]. The crane will provide Lift On/Lift Off (LO/LO) capability for transfer of cargo. In the normal mode of operations, the motion compensated crane is extended transversely from the warehouse and is expected to handle standard container loads up to sea state 4 with an estimated throughput expected to at 30 TEUs per hour. It is envisaged that the frequency of flight operations will be higher compared to the frequency of alongside transfer of cargo, hence a key factor in the deciding the crane system is the level of intrusion into the airspace above the flight deck. The chosen crane is a smaller version of MOB's crane, and has minimal impact on flight operations as it can be recess into the warehouse deck and in its normal mode, will only operate in the vertical space below the flight deck as shown in Figures 62 and 63.

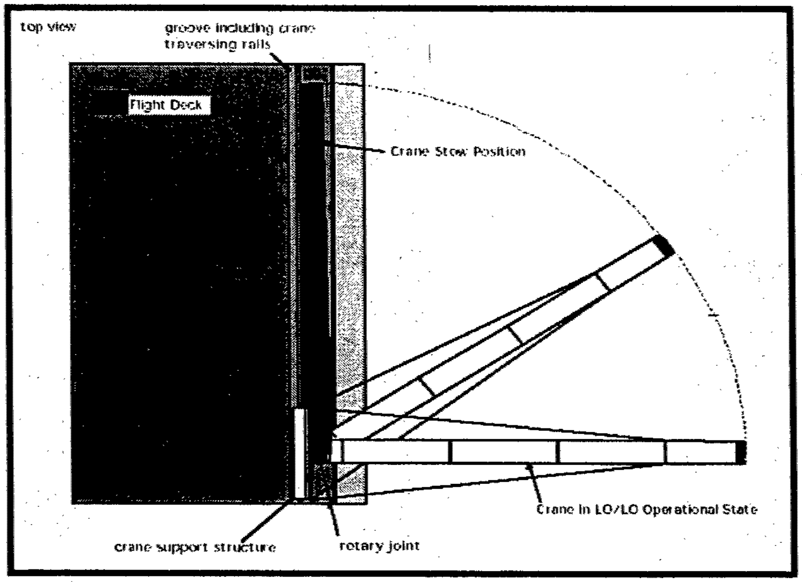


Figure 62. TOP view of Cargo Crane stowage into the warehouse (Source [51])

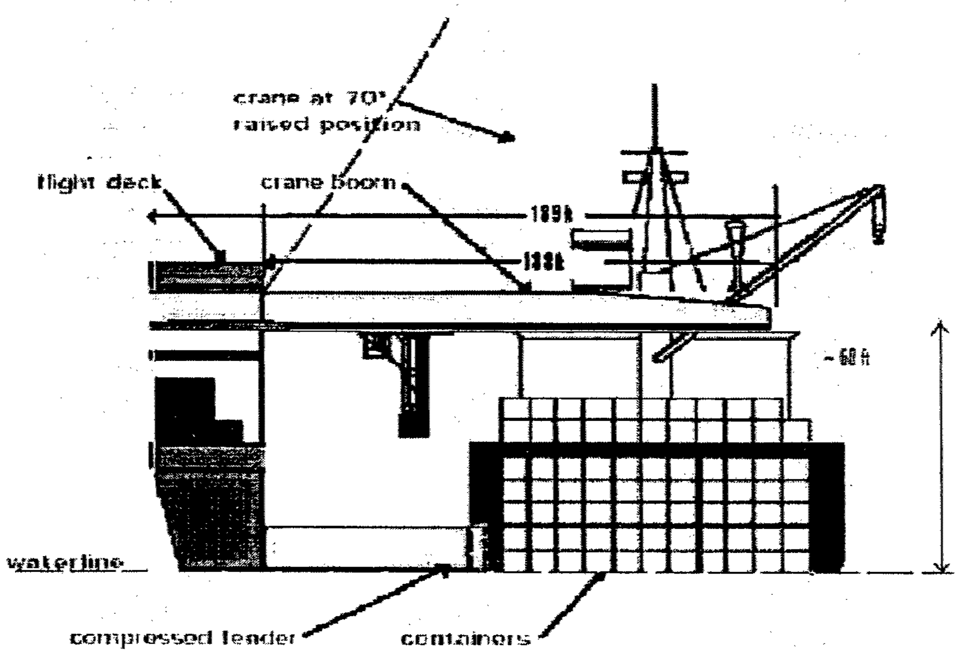


Figure 63. Schematic side view of Cargo Crane Stowage into the warehouse (Adapted from source [51])

The crane will have the ability to unload cargo from merchant/CLF ships and handle up to 23 LT load (up to maximum TEU loads) from the far beam of the supply ship. It traverses longitudinally along rails(200 ft) that runs below the deck edge through the warehouse and into part of the Hangar to allow maximum longitudinal access of the cargo hold of the supply ship. In the non-standard mode the crane boom can be luffed or hinged so that it can be raised up to a maximum of 70° when supply ships are docking next to the fender.

A higher hook will allow for the crane to handle higher shipboard stacking of containers height. However, it is deemed that the loss in flight deck space imposes a higher penalty on operational efficient than a lower hook height. The maximum water line to hook height is approximately 60ft (19.8m) based on a design waterline of 40 ft draft. This will only allow retrieval of containers that are stacked one high from most commercial type ships. The crane will need to be luffed to reach higher stack heights incurring a drastic reduction in lift speed and reach of the crane. On the supply variant of the Sea Force there is an alternate option of placing a modularized crane on a pedestal mounted on the flight deck. This will resolve the issue of low hook height but at a penalty of flight deck spots. Existing crane capabilities typically operate at one lift (TEU)every 7 minutes. The estimated throughput of the crane is expected to be in the region of 29 TEUs per hour[3], and with motion compensation the crane will be able perform to its stated specifications up to sea state 4.

3. Warehousing

The allocation of volume for the warehouse facilities was influenced by several factors. The warehousing system had to be

modularized in order to facilitate selective offload, and there was a need to leverage on automation in order to reduce manning. The location of the warehouse had to be close or easily accessible to the flight deck since expeditious in-stride sustaiment will be most efficiently distributed via aerial replenishment (VERTREP). In addition, the location of the warehouse had to facilitate the transfer of containers via crane and provide easy access to the Hangar Bay, well deck and LCU ports. With these considerations in mind, the location of the warehouse was positioned on the main deck, just forward of the hangar bay. The allocated area for the warehouse is a rectangular shape compartment with a width of 90 feet, a length of 305 feet, and a height of 35 feet. The total warehouse volume is 960,750 ft3.

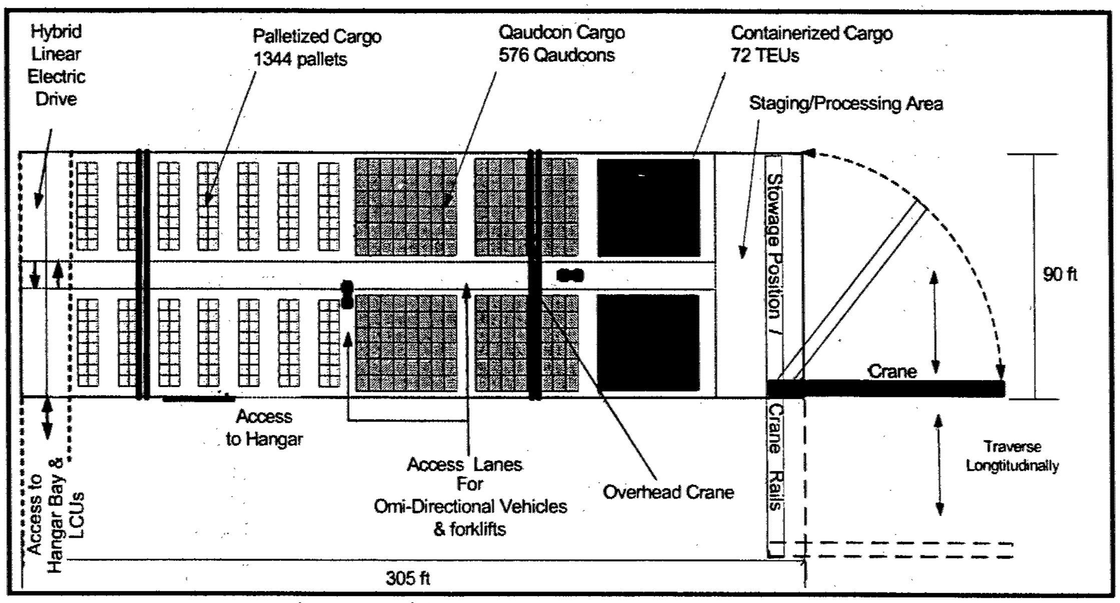


Figure 64. Presents a proposed layout of the warehouse area.

For the warehouse, the prudent use of automation enhances the efficiency logistical support and allows selective offloading. An electronic gantry is located across the stowage area, where all cargo will be electronically scanned prior to entry into the

warehouse. Once inside the warehouse, the two overhead cranes have access to any point in the warehouse. The center transit lane is 10 ft wide and allows automated access by omni directional vehicles and forklifts which moves the cargo from the staging/processing area to storage or the Linear electric drive transporters.

Since access to the supplies is through the overhead cranes, the key for selective off load would be to segregate each type of supplies so that one section would be of a particular material. This is facilitated by means of electronic tagging of each TEU and Quadcon upon entry into the warehouse. Drawn from research done by the Science Applications International Corporation, a basic passive electronic tagging system(RFID) consists of installed transponder tags and a reader system as depicted in Figure 65.

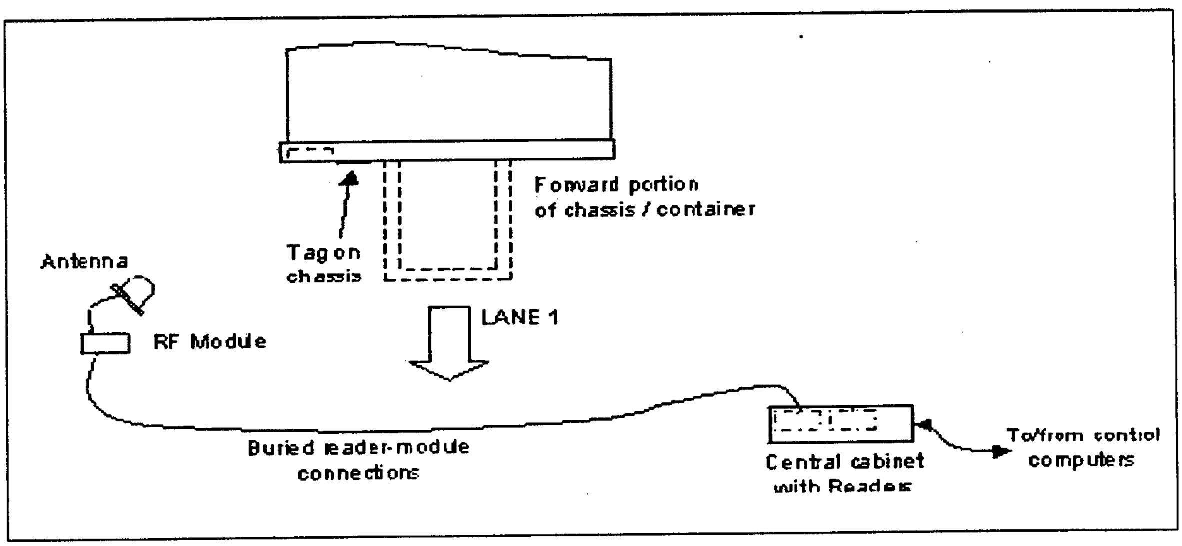


Figure 65. Figure V-G-7 RFID Electronic Tagging systems

Once the cargo is onboard the ship, through either mode of transfer, the ship layout has been arrange to allow for multiple unfettered access from the entry point to its intended storage

locations in the hangar, ammunition magazine, warehouse staging area or the well deck as shown in Figure 66.

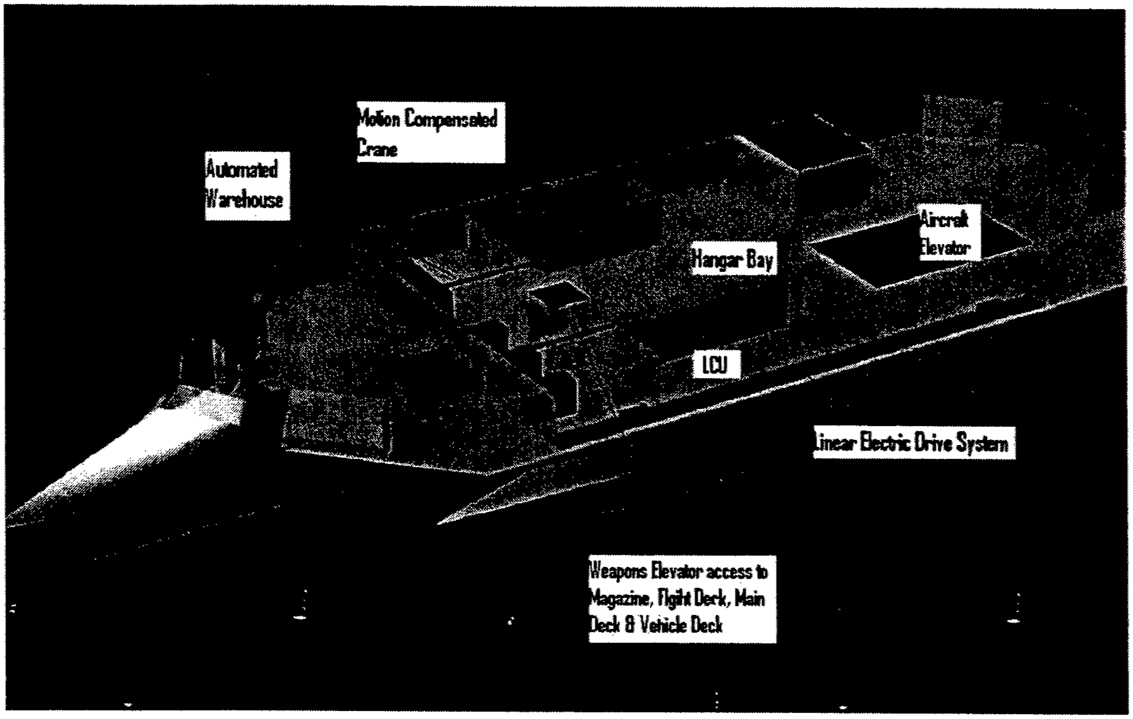


Figure 66. Internal arangments of the Main Logistic hardware

4. Automation

In order to perform the myriad logistical requirements demanded of a sea basing ship, the automated system employed onboard the ship must integrate the various logistic hardware, cargo stowage and handling systems. The system must provide a unifying solution to automate and monitor all the intra ship logistic functions such as planning, process, coordination and task assignments. The automation algorithm should support all internal cargo movements from the deck edge, wet well or flight deck to the intended storage location for reissue and retrograde handling. In a reduce manning environment onboard the Sea Force,

a large part of the material handling systems will be process and moved by autonomous omni-directional vehicles, the automation system must coordinate the vehicle paths and direct vehicles and loads to the intended locations to ensure that optimal use of cargo handling resources onboard. The "Unified Control Solution [53]" currently under research by Orbital Inc for NAVSEA, is a potential candidate for implementation onboard the Sea Force. The Unifying Control Solution by ORBITAL Inc. is a culmination of four software algorithms describe below.

Orbital Research Intelligent Control Algorithm (ORICA) is an adaptive predictive controller software package that addresses the limitations of modeling complex multiple input multiple output (MIMO) systems by precise mathematical relationships. From explicitly or implicitly base estimation of the parameters describing the model of the discrete time system, control laws are derived using adaptive predictive controllers and implemented in the over-arching logistic system.

Multi-Resolution Path Planning System (MAPPER) provides path planning guidance to the multi autonomous vehicles operations found onboard the Sea Force's warehouse, magazines and Hangar bay. The system allows path guidance when "explicit configuration space computation is not feasible [53]"

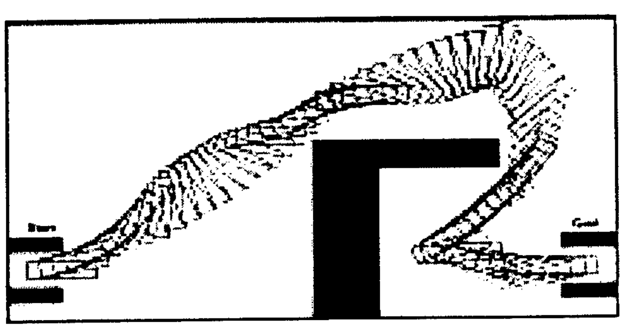


Figure 67. MAPPER motion plan for vehicle in 2D workspace. Vehicle movements are combined to plot a course around the obstacle and into the goal space.

BioAVERT (Biologically Inspired Avoidance System) Multi vehicle operations within the dynamic environment onboard the Sea Force requires each vehicle to have an enhanced sensory perception and knowledge of its surroundings and other vehicles. Collision avoidance becomes absolutely critical. Orbital has modeled its collision algorithm by "mapping of the neural circuit governing an insect's predatory escape response[1]".

Emergent Behavior-SWARM Intelligence handles the coordination and tasking of multiple vehicle based on the concept of simple rule based commands rooted on the emerging behavior of decentralized intelligent objects operating in a dynamic changing environment.

The intra ship logistical automation provided by Orbital's Unifying Control Solution algorithm would influence positively the ability to tap into the network based joint logistics information system. Sea basing necessitates that the intra ship system must interface and share the same information systems as Joint Theater Distribution. In order to allow in stride sustainment to forces ashore, the ship to force logistic system will need to be fully integrated with the Global Combat Support System (GCSS) to facilitate timely and efficient distribution of logistics through focused management and demand reduction. An extension to the intra ship system required to interact with the external GCSS can be modeled after Tloads/Cloads[6] which conducts discrete event" simulations to analyze the

effectiveness of the sea force in performing and execution of the functions of a sea base distribution and logistics hub to support the MEB ashore. An illustration of the graphical output derived from Tloads/Cloads is shown below in Figure 68.

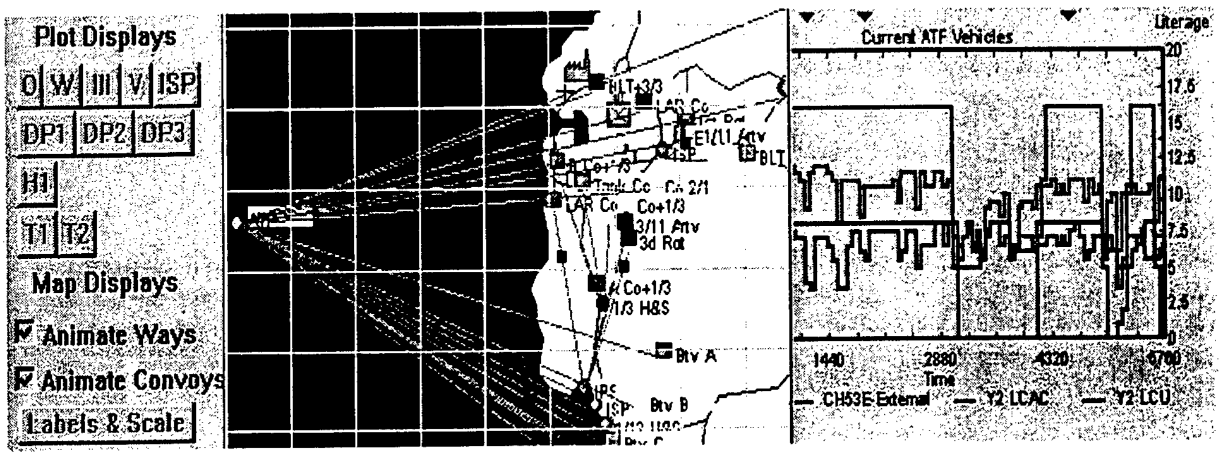


Figure 68. Illustration of Tloads/CLoads Simulation Display (Source [54])

5. Indefinite Sustainment

In order to facilitate indefinite sustainment of the forces ashore, the Sea force will need to have these fundamental capabilities;

1. Comprehensive situational knowledge on intra and inter ship logistics and awareness of real time battle space logistical demands.

2. Facilities to accommodate/track/store the inflow of logistics support from a variety of sources like and efficient distribution means to deliver to the end-user pre-emotively or on demand.

From the onset, a key factor of Sea Force design has been the need to serve as the conduit for logistic storage and distribution to achieve indefinite sustainment. The Sea Force

C4I facilities are intricately plug into network centric warfare and the Force Net as elaborated in the Chapter on Combat Systems. This allows Sea Force to have comprehensive battlespace awareness of the logistic levels and end-user demands can be routed to and monitored by Sea Force.

The triple tram-line permits 16 aircraft spots and simultaneous STOVL and rotary wing operations. With increasing payload and endurance offered by future heavy lift rotary aircraft, aerial delivery will remain a predominant factor in the ability for the sea base to ensure enduring sustainment for the ground forces ashore. It is envision that aerial delivery will provide the most expeditious means for logistic distribution. The ship also has the ability to accommodate simultaneous LCAC and LCU operations in the well deck and side ramps between the hulls in calm environmental conditions, thus increasing the logistic throughput ashore. Even though in the Sea Force operational concept, a supply variant of the Sea Force provides direct sustainment to the MEB beyond the first thirty days, all Sea Force variants will have the ability to interface with legacy and CLF ships giving the Sea Force the added niche in maintaining indefinite sustainment and contributing to the reduction of footprint ashore.

H. MANNING ANALYSIS

The team identified three major areas that will have the greatest influence on the overall manning requirements of the ship, namely General Quarters requirements for watch stations, maintenance requirements and logistics operations requirements. The complete manning break down can be found in Appendix D.

1. General Quarters

General Quarters requirement for watch station was determined through an analysis of the functionalities required of the ship in support of the demanding STOM operations, and consequently determined the minimum number of watch stations required to provide both efficient and effective support of the STOM operations. The minimum number chosen for the watch stations was also influence by the assumption that significant automation will be available by the year 2020 to enable reduced manning. In example, the watchkeeper at the machinery control room is provided with a Multi-Modal Watch Station (MMWS) [57] which provides real time condition monitoring of all machinery in the propulsion compartment with CCTV located at strategic locations to enable him to virtually walk through the spaces and in addition zoom in on areas that his naked eyes may be lacking. The MMWS would allow machinery to be started/shut-down or valves to be open/close remotely, alarms warnings on potential problems to be flagged with intelligent diagnostics advise that prompts the watchkeeper on the necessary actions to take. These are all within his fingertips. The watchkeeper will only activate the maintenance crew on standby if manual intervention is required.

2. Maintenance

Maintenance requirement includes determining the manning required for shipboard level maintenance, and for the operation of BFIMA. For shipboard level maintenance, it is envisage that low maintenance designs will be incorporated in the areas of flight deck, DC and engineering for reduced manning. The

building blocks of this design include Conditioned based maintenance (CBM) that reduces the need for Inspect and Test functions which account for 75% of PMS tasks, Integrated Electric Drive that eliminates the need for shaft seals and bearings between compartments, Pod drives that has an external motor assembly that is easy to remove and uses geared electric motors rather than hydraulics to rotate steerable pods, Power Electronic building blocks that enable standardized, modular assembly of multi-function power modules and controls, and a ship wide area network for automated identification technology in life-cycle and configuration management and component tracking [58]. In addition, it shall be planned such that routine visits by tiger teams from the navy and MSC teams will perform the bulk of maintenance requirements.

3. Logistics

Logistics operations requirement includes selective off-load/on-load of vehicles, general stores and ordnance, food service, and medical care for MEB forces ashore. Automation technology in the area of materiel handling will be implemented to enable selective off-load/on-load capability and at the same time reduce the manning requirements for such operations. Reduction in manning for food service can be reduced through Advance food technologies that require less preparation and cooking times than "cook from scratch" products. New efficient construction food service operations will also enable minimal manning, such as clustered storerooms that provide for faster and more efficient breakout of stores, centralizing the food service operation in one area on the ship also reduces workload by collocating the general mess, CPO and Wardroom galley, and

placing the bakery and scullery in close proximity to this centralized galley also reduces manpower requirements [59].

Perhaps the most significant reduction in manning is in the area of damage control. On the one hand the ship will be benefit from the current technological pushe such as the Damage Control Automation for Reduced Manning (DC-ARM) program and the Advanced Damage Countermeasures (ADC) program. Based on the success of these programs, it is anticipated that by the year 2020 there will be an intelligent Supervisory Control System (SCS) with capabilities such as real-time damage assessment, quick automated response to isolate damage, automated stability monitoring with remote ballasting control, advanced diagnostic recommending best course of actions to the DCA, and additionally interfaces with SWAN to enable anticipatory responses to imminent missile hit. On the other hand the ship DC party will be a secondary role that will be assumed by maintenance and deck personnel.

I. COST ANALYSIS

SEA Force's acquisition cost was based on a weight scaled model similar to that employed in the 2001 TSSE SEA ARCHER study 0. This model used CERs from the S-CVX study conducted in 1998 [60]. The Sea Force model incorporates non-traditional weight fractions, high cost for specialized equipment required to meet the ship's missions, and one time costs for Government Furnished Equipment (GFE) that is presently under development. Cost estimates for SEA ARCHER's specialized equipment included in the cost model are summarized in Appendix F.

The acquisition cost for Sea Force is estimated at \$3.54 billion and its accompanying airwing cost is \$1.665 billion.

This is nearly two times the predicted cost of LHD-8 ($1.8 billion). If the cost estimate were simply based on the weight, neglecting the specialized materials and systems and non-standard weight fractions, Sea Force would be a fraction of the cost. Cost was driven by several factors including hull and structural requirements, combat systems, command and control systems and automation. Cost was given one of the lowest priorities in our design philosophy to allow for maximum exploration of new technologies.

Sea Force contains some innovations precluding a simple comparison to current ships whose primary mission is Amphibious Warfare. First, in an effort to reduce manning, automation was included in the design wherever feasible. A significant effort was given to automation of the aircraft handling, weapons handling, cargo handling and damage control functions of the ship. These are traditionally manpower intensive operations. Automation costs include overhead cranes and conveyers, elevators and the software required to manage the warehousing, ammunition handling, and flight deck capabilities. The cost of the software required to achieve this automation was estimated to be 75 percent as much as the cost of the hardware.

The single biggest cost-driver in the Sea Force design was hull from, though not far behind was the combat systems suite. The requirement to achieve STOM, support and carry an entire MEB's worth of equipment, and to sustain in a sea base environment for a minimum of 30 days drove a non-conventional hull form and structural requirements that resulted incredible added weight and cost. A thirty percent increase in hull construction was applied to account for the tri-hull design. With little raw data available in the area of tri-hull

construction, the design team could only provide a rough estimate of the cost.

Sea Force's combat system and weapons suites are more robust than those on a present day LHD. The intent of a potential "overdesign" in this area was to ensure the requirements were met for the ship's offensive and defensive capabilities and to explore the feasibility of incorporating this combination of new technology. As seen in the weapons/sensors section of this report, some of Sea Force's sensor and weapons systems include a digital array/volume search radar, an advanced electronic warfare suite, an infra-red search and track system and electro-optical system, NULKA launchers, SEA RAM, free-electron laser, and rail gun. The combat systems and weapons suites have secondary cost impacts in that they require a significant amount of energy and first time integration cost, both of which drive up cost. This energy demand forced a design with more power generation and a higher electric plant cost. Integration was estimated to run between $200-$300 million.

J. HABITABILITY

1. Berthing Facilities

A habitability analysis based on the Shipboard Habitability Design Criteria Manual [61&62] was conducted for the berthing requirements of the ships crew and embarked troops. This analysis serves as the initial estimate of the berthing space requirement that is necessary for estimating the volumetric requirements of the ship as well as the internal layout. More

in depth analyses would be conducted on subsequent iterations of the design.

In this initial analysis, every Sea Force ship is configured to support the MAGTF Commander. In addition, the ship is also configured to support a Flag Officer and the associated supporting staffs. The accommodation for the Flag Officer will serve as the accommodation for the JTF Commander and his/her staffs should the need arise. Senior Officers in this respect are of the rank O-5 and above, while CPO's are those with rank E-7 and above. The berthing space allocation per person is based on the space required for the bunks, the number of tier per bunk, the necessary separation between bunks and stowage requirements. Senior officers and above are accommodated in single tier bunk while junior officers and Ship CPO are accommodated in double tier bunks. Ship Enlisted and Troop CPO are accommodated in three tier bunks, while Troop Enlisted are accommodated in four tier bunks. For officers, the berthing space allocation includes additional space for unobstructed walking and working requirements. The breakdown of the berthing space allocation is tabulated in Table 36.

In order to achieve space savings and to augment modularity, berthing spaces are designed to be in standard modules. These modules would facilitate modular construction and enhance conversion of troops berthing modules to other useful spaces. The number of personnel group into each accommodation module was based on what the team felt to be reasonable and at the same produce modules of sufficiently large size to generate the advantages of modularity. Sanitary space entitlement was then added to each module based on the number of personnel in each module and their ranks. For CPO and Enlisted personnel, lounge space was included into each module to enhance

	Number	Area (Sq Ft)
Ship CO	1	138.1
Senior Officer - Ship	10	108.1
Junior Officer - Ship	40	62.4
CPO - Ship	41	27.4
Enlisted - Ship	632	16.6
MAGTF Commander	1	138.1
Senior Officer - Troop	30	93.1
Junior Officer - Troop	240	52.6
CPO - Troop	270	23.6
Enlisted - Troop	2459	14.7
Flag Officer	1	138.1
Senior Officer - Flag staff	10	108.1
Junior Officer - Flag staff	10	58.4
CPO - Flag staff	10	27.4
Enlisted - Flag staff	15	16.6

Table 33. Berthing space allocation.

the quality of life within each module. The breakdown of the space allocated per module is as tabulated in Table 37. For officers, the lounge and messing spaces are combined to form the Wardroom.

	Number of personnel per module	Number of tiers per berth	Number of modules	Area of module (sq ft)	Total Area (sq ft)
Ship CO	1	1	1	159	159
Senior Officer - Navy	5	1	2	549	1,099
Junior Officer - Navy	10	2	8	642	5,135
CPO - Navy	10	2	9	357	3,212
Enlisted - Navy	84	3	10	2,009	20,090
MAGTF Commander	1	1	1	159	159
Senior Officer - Troop	10	1	3	949	2,846
Junior Officer - Troop	20	3	13	1,077	13,998
CPO - Troop	30	3	10	956	9,565
Enlisted - Troop	124	4	20	2,712	54,249
Flag Officer	1	1	1	159	159
Senior Officer - Flag staff	5	1	2	549	1,099

Table 34. Module space allocation.

2. Medical Facility and Hospital

The Navy provides second echelon afloat care on either amphibious transport ships or aircraft carriers. In each amphibious task force, usually at least one amphibious ship is designated to provide the second echelon care. These ships can

have up to six operating rooms and can hold between 200 and 600 patients. These are usually bunks that were previously occupied by the troops before the assault [63]. Sea Force ships however will have dedicated medical facilities and hospital to sustain the MEB ashore indefinitely. In this respect, the Sea Force ships will be configured to provide third echelon afloat care that is currently performed by dedicated Hospital Ships. Each Sea Force ship will have a dedicated hospital with a capacity of 500 beds (80 intensive care, 20 recovery, 280 intermediate care, 120 light care). The medical facilities include six operating rooms, two dental operating rooms, and a pharmacy.

VI. OPERATIONAL CONCEPT

A. VISION STATEMENT

As stated in the introduction, the objectives for the design team were to develop a ship or family of ships that incorporate numerous capabilities not inherent in our current expeditionary forces: STOM, indefinite sustainment, selective offload, reconstitution of forces ashore, long range Naval Surface Fire Support (NSFS), and an increased capability in command and control. These objectives combine to minimize the Marine footprint ashore and are accomplished via throughput, responsiveness, storage capacity, and flexibility. One of the major challenges associated with a Sea Based operation involves getting the replenishment from a forward logistics site (FLS) to the sea base for greater than 30 day sustainment. The FLSs currently in use are Diego Garcia, Roda, and Guam from which the three major Maritime Prepositioning Force squadrons operate. Any of the MFP ships can reach a conflict within seven to ten days from these sites. However, the present day MPF ships do not carry the Marines *and* their equipment. A friendly air base near the port or area of conflict is required to bring them together. Presently, securing a port or beach requires a permissive and benign environment. The complexity, instability and uncertainty associated with securing foreign ports in today's constantly changing environment drives the need for a sea based solution.

One example of the potential problems associated with securing a friendly port is offered in figure below. A photo of part of the offloaded equipment from the First Marine Expeditionary Force (I MEF) just prior to the start of Operation Desert Storm in February 1991 is shown in Figure 69. The pier

pictured in this figure was targeted by an Iraqi scud missile. Fortunately, the missile missed by about one mile. A ship underway, at sea, over the horizon is harder to target than a stationary pier. With a very small selection of overseas ports (11% for LMSR type ships), however, it is imperative to find an alternative solution.

Figure 69. Fist Marine Expeditionary Force Equipment Offload [64]

The vision for Sea Force is to incorporate the MPF concept with that of a present day Amphibious Ready Group (ARG) or Naval Expeditionary Strike Group (NESG) in order to build a platform that has the power to support the spectra of conflict for the USMC and Joint forces in the following symmetrical and asymmetrical threat areas: terrorism, peacekeeping, refugee management, non-combatant evacuation operations, amphibious assault and sustained operations ashore, amphibious raid, peace enforcement, disaster relief, and consequence management. The Sea Force concept utilizes one ship as the big deck platform in

an NESG once the LHD and LHA class ships are phased out of commission. Sea Force will operate with one legacy platform (LPD-17) to form an ARG/NESG. Figure 70 shows a comparison of the legacy platforms in the fleet and their predicted decommissioning periods.

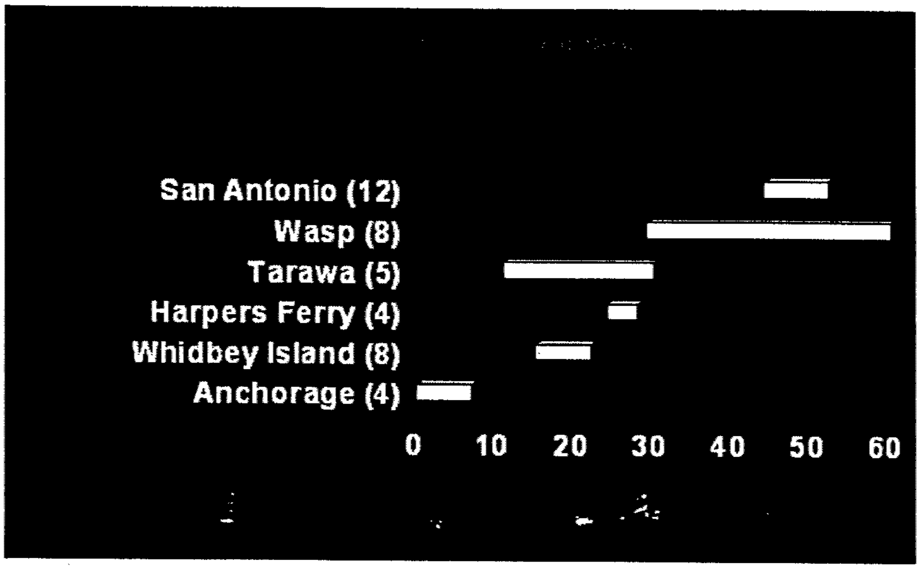


Figure 70. Legacy Ship Decommissioning Timeline

LSDs can be maintained in the traditional ARG with LHAs until both reach the end of their predicted lifetime (around the year 2030). The increased capabilities of the LHD class allow it to operate with only one or two additional ships to support a MEU vice the two to three that and LHA needs. A two ship ARG could thus be achieved with and LHD and one of the new LPD-17 class ships. In support of typical force structure and deployment cycle operations, the Sea Force can deploy with an NESG. When larger conflicts arise that require sustained sea base operations, one or more Sea Force NESGs can fully resupply and drive towards the AOA. Additional Sea Force ships that are prepositioned in FLS sites can merry with the required Marines

and drive to meet the NESGs on station. The complexity arises when trying to merry the Marines with the ships, as there are a large number of Marines to transport. One solution to this problem is the HSV.

The final loop in this concept is achieved when Sea Force ships configured for supply and sustainment arrive on station beyond the initial 30 day sustainment window. With a modular design, approximately 5.7 million cubic feet of space can be converted for cargo, pallets, ammunition and liquid stores. This supply configuration Sea Force ship would retain many of the capabilities required to be part of the sea base in the areas of command and control, well deck, and flight deck. Thus, the ships on station can lift on and lift off supplies, perform STOM, and resupply each other directly from the supply configuration ship. If required, however, MSC ships can be incorporated into the sea base. Sea Force is capable of ship to ship transfer with the MSC ships, although the project was designed to minimize this activity.

As per the SEI Strategy Paper (dated 02AUG02), the following key issues are assumed to be standard operation for the Sea Force design:

- Legacy platforms projected to remain operational through this timeframe are not retired early.
- All Marine new aircraft and land vehicle purchases currently projected to be available in this timeframe are fielded on schedule.
- A MEB sized MAGTF's sustainment requirement remains relatively constant between the present and 2015-2020:
- A MEB sized expeditionary forcible entry operation will not take place without the **support of at least one CVBG**.
- Future Amphibious Readiness Groups (ARG) deploy as **Expeditionary Strike Groups** with surface combatant

escorts as envisioned in the CNO's Sea Power 21 operational concept.

The design team envisioned a typical mission as follows: The first wave of launches takes place from the decks of the Sea Force ship consisting of the preponderance of transport or heavy lift helicopters and MV-22s. These platforms will always operate under air cover from the fixed-wing Carrier Strike Group fighter and escort aircraft and insert rifle companies and their respective weapons platoons. Before the first waves launches, fully loaded attack helicopters will be positioned in order to mass the most combat power at the decisive time and place. The triple-tram design of Sea Force permits this mass of combat power. Simultaneously, the first wave of water transport craft launches for positioning of LAR, Tank, and Weapons companies ashore. AAAVs may also launch from the stern ramp allowing rapid closure of a second-echelon waterborne force.

B. LOADOUT AND EMPLOYMENT

Six Sea Force ships shall have the capability to transport the notional Marine Expeditionary Brigade (MEB), defined in Chapter II, and its associated weapons and equipment to the theatre of operations and enable the MEB to perform Ship-to-objective maneuver (*STOM*) [6]. In addition, the six Sea Force ships will carry sufficient provisions and ordnance to sustain the MEB ashore for 30 days and will have throughput ability for indefinite sustainment. These requirements are evenly distributed among the six Sea Force ships such that each ship is able to have the full spectrum of capabilities required for one-sixth of the MEB force, with 30 days initial sustainment, and indefinite throughput ability. The load-out for each Sea Force ship was thereafter determined. The total payload of each ship

is 17,848 long tons taking up a volume of 4,309,954 cubit feet. For a full listing of all MEB equipment read Appendix G.

	Number	Weight (LT)	Footprint (ft^2)	Volume (ft^3)
LAV	4	51	741	12,147
AAAV	19	601	8,824	185,310
M1A1	10	604	3,840	72,960
HMMWV (TOW)	12	29	1,274	15,293
M198 How	5	35	1,855	35,243
Sub-Total		**1,321**	**16,534**	**320,953**

Table 35. Major Weapons Load-Out of Each Sea Force Ship

	Number	Weight (LT)	Footprint (ft^2)	Volume (ft^3)
Armed HMMWV	10	27	1,062	9,558
LVS Power Unit	19	215	0	0
LVS Wrecker	1	13	304	5,168
LVS Trailer	9	64	2,736	46,512
5 Ton	47	450	9,400	181,232
P-19	2	30	666	18,648
HMMWV	79	183	8,390	100,678
MRC-110	11	26	0	0
MRC-138	10	23	0	0
MRC-142	4	9	0	0
M970 Refueler	5	34	3,188	86,700
Sub-Total		**1,074**	**25,745**	**448,496**

Table 36. MT/Communications Equipment Load-Out of Each Sea Force Ship

	Number	Weight (LT)	Footprint (ft^2)	Volume (ft^3)
ROWPU	7	1,794	459	365
RTCH	3	113	1,229	5,522
D7	3	137	732	2,274
EBFL	8	2,629	1,322	1,603
TRAM 644E	7	1,619	1,355	2,129
M9 ACE	1	5	215	1,906
MC1150 Tractor	2	25	222	1,053
Line Charge	3	145	0	0
Watercons	19	23	988	208
Fuelcons		0	0	0
Sub-Total		**6,488**	**6,521**	**15,060**

Table 37. CSS Equipment Load-Out of Each Sea Force Ship

	Number	Weight (LT)	Footprint (ft^2)	Volume (ft^3)
LCAC	3	399	13,186	
LCU-R	2	1,030	14,658	
Sub-Total		**1,428**	**27,844**	

Table 38. Sea Transport Assets Load-Out of Each Sea Force Ship

	Number	Weight (LT)	Footprint (ft^2)	Volume (ft^3)
HLA	4	53	42,120	1,193,260
AH-1Z	4	16	9,908	144,333
UH-1Y	4	18	9,908	147,635
MV-22	16	211	81,365	1,471,347
STOVL JSF	6	54	6,334	110,849
UAV	2	0	0	0
Sub-Total	36	**353**	**149,636**	**3,067,423**

Table 39. Air Assets Load-Out of Each Sea Force Ship

	Number	Weight (LT)	Footprint (ft^2)	Volume (ft^3)
Provisions	30 days	424		50,667
Ordnance	30 days	3,069		183,333
Fuel - GCE	30 days	1,236		53,472
Fuel - ACE	30 days	3,883		170,550
Sub-Total		**8,613**		**458,022**

Table 40. Stores Load-Out of Each Sea Force Ship

The notional MEB force also includes the Expeditionary Airfield (EAF), Field Hospital, and Mobile Construction Battalion [2] that may not be readily deployed for *STOM* [6] operations. Nevertheless these assets might be required in operations that call for the employment of a Marine Expeditionary *Force* or joint and/or combined assets. It was therefore decided to load these equipments on the supply variant of Sea Force. The load-out for the supply variant will vary according to mission needs. For more information on the supply variant load out read the chapter on modularity.

C. TIMELINE AND KEY ASSUMPTIONS

The Sea Force ship design will have the ability to build, project, and sustain combat power ashore. A MEB-sized force will be comprised of six ships. The force will be scalable to the type of operations. Two Sea Force ships will provide all the equipment, personnel, and support for a MEU-sized force for up to 30 days. The Sea Force ship can also be employed as an alternative to the LHA(R). In this manner, the Conceptual architecture would employ the Sea Force ship with legacy

amphibious assault ship assets in the Naval Expeditionary Strike Groups (NESGs).

The TSSE ship design features a highly automated logistics requisition and distribution management system that reduces human input, accelerates materiel movement, and reduces costs. The ship's warehousing capabilities include storage for over 325,000 ft^3 of provisions, ammunition, and spare parts. Selective on-load and off-load will allow the Sea Base to reduce inventories and provide for faster retrieval and delivery of supplies. This feature, combined with the highly automated nature of "just in time" logistics, will allow a management by exception approach. Enhanced knowledge of in-transit inventories through total asset visibility will refine allocation of transportation resources, improve item availability and increase velocity of materiel movement through the system.

Using Sea-Based Logistics as the primary design philosophy, the ship will provide an integrated over the horizon floating distribution center and workshop providing indefinite sustainment. Reducing or eliminating the logistics footprint on shore is the primary objective of Sea-Based Logistics. Reducing the logistics footprint ashore will reduce double handling of materiel by cutting out the intermediate step of establishing shore-based logistics activities and eliminating the operational pause associated with that effort. Each of the TSSE design ships will have 16 helicopter spots, maximizing air operations and assets. Through massive airlift, forces ashore will not be required to protect logistics bases and extensive interior lines of communication. This will allow greater operational initiative and maneuver freedom. Each of the Sea Force ships will be able to carry and operate 4 LCACs , and 2 LCU(R) that will provide transport, for land mobile combat service support

forces, will discharge logistics trains that will operate with maneuver forces, allowing lines of communication to close behind them. Replenishment of bulk fuel, water and supplies will be accomplished vertically or via surface transport on reopened ground supply routes. Caches of logistics support items will be established at selected locations for rendezvous with maneuver forces. Forward arming and refueling points (FARPs) will be established through aerial delivery or by mobile ground units deployed ashore.

Sea Basing maintenance for aviation assets, ground combat equipment, and the NESG will be provided in order to maintain high op-tempo for extended periods and the ability to reconstitute equipment after an operation has been completed. Other special functions such as logistics-over-the-shore systems, medical support, and specialized sustainment will be integrated as required. The TSSE design also features modularity and a growth margin that will enable it to interface with future platforms as they are designed and fielded.

Shuttles with strategic and inter-theater lift and worldwide commercial distribution systems will provide indefinite sustainment. The Sea Base ships will be able to transfer standard 20 ft containers, unpack, and store the supplies. The Sea Base will essentially serve as a primary distribution center with the capability to transship cargo from containers and distribute ready-for-issue materiel to forces ashore. While the principal focus of Sea-Based Logistics is sustainment of operating forces, facilitating the build-up of combat power ashore is well within its capability. As missions expand, Sea-Based Logistics can support the closure of joint and coalition forces arriving in theater. As littoral operations enter new phases, Navy and Marine Corps Forces will have the

unique capability to rapidly reconstitute at sea for redeployment to follow-on operations.

The Conceptual architecture for a notional MEB size force in 2015-2020 will be robust, flexible, and a potent force enabler -- capable of projecting combat power deep from the sea to deep inland. The Navy and Marine Corps team will have the capability to launch from 75 NM from the sea to 200 miles inland within 24 to 48 hours upon arriving at the launching area. The future conceptual expeditionary force will be scalable and capable of operating jointly with Carrier Strike Groups (CSGs) and allied forces. Additionally, the Conceptual architecture for a notional MEB will have the ability to sustain itself for 30 days, as well as provide indefinite sustainment to the forces ashore.

Logistically, the Conceptual architecture will be re-supplied by 3 dedicated shuttle ships as well as commercial and other logistic ships. The 3 shuttle ships will have similar characteristics as the 6 Sea Force ships that make up the Sea Base, but will provide a logistical support role only. The 3 shuttle ships will transit between the offshore base and the 6 Sea Force ships, indefinitely sustaining the Sea Base as needed. The transfer of supplies to the combat forces ashore will come from both air and sea transporters. Ideally, the MV-22 and the conceptual Heavy Lift Aircraft will be the main logistic supplier to the combat forces ashore. In the event that air transporters cannot meet the daily re-supply requirements to the combat forces ashore, then both air and sea transporters will be utilized.

The requirement to conduct beach landings remains because AAAV and the M1A1 are too heavy transport to the objective by air. Heavy Lift Landing Craft Air Cushion (HLCAC) and Landing Craft Utility (Replacement) LCU(R) with their enhanced

capabilities will give the expeditionary force of the future an over-the-horizon strike capability -- unlike amphibious operations of the past. An over-the-horizon capability makes the Sea Base less vulnerable and enhances the element of surprise. With the added capabilities of the future Conceptual architecture for a notional MEB, the enemy will have to disperse their forces to cover a larger area.

Figure 1 depicts the flow of a Conceptual expeditionary warfare concept. The notional MEB will arrive at the arrival and assembly area from forward deployed locations in the Mediterranean Sea, Persian Gulf, Indian Ocean and/or Western Pacific. Unlike amphibious operations of the past, the Conceptual design does not rely on friendly ports or airfields near the operation. The Conceptual Sea Base projects and

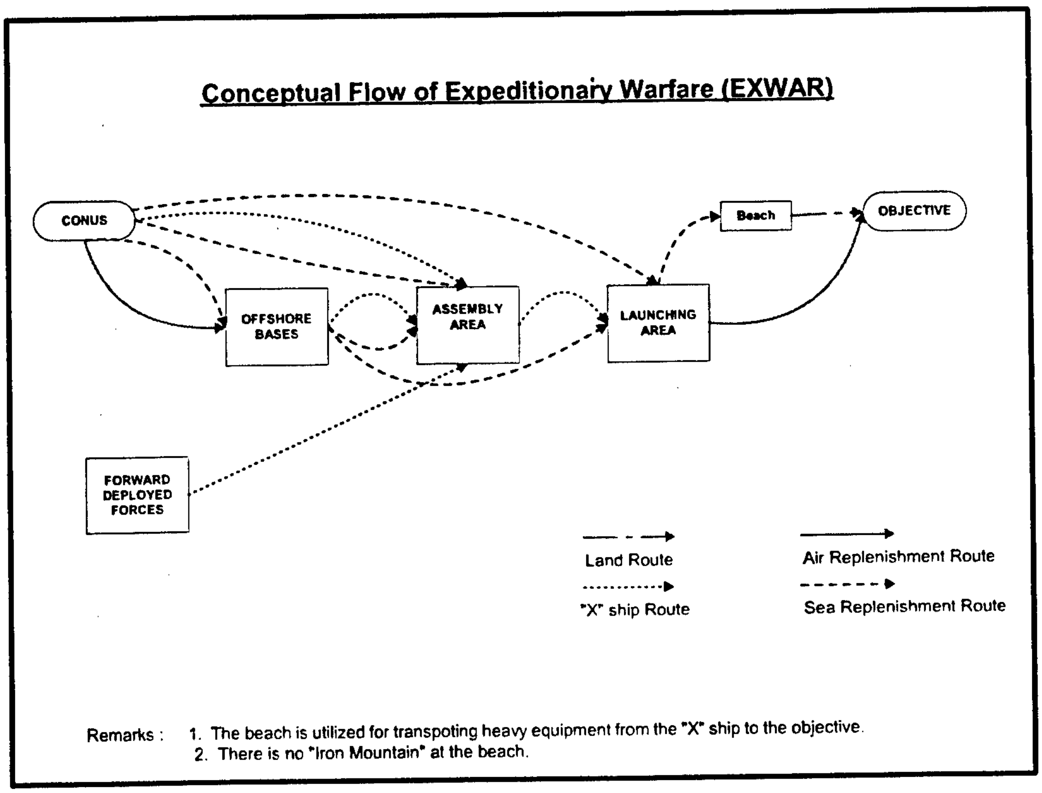


Figure 71. Conceptual Flow of Expeditionary Warfare

sustains power entirely from the sea. The notional MEB will move to the launch area and project combat power ashore by both air and sea transporters. Air transporters will carry the notional MEB directly to the objective while sea transporters will project forces and equipment to the objective via a beach landing area with minimal operational pause operational pause.

D. IMPACT ON PRE-POSITIONING CONCEPT

The Maritime Prepositioned Force (MPF) consists of three Maritime Prepositioned Squadrons (MPS) positioned around the world. The MPS ships are configured to transport supplies for the U.S. Marine Corps. The program was first implemented in the mid-1980s. MPS shipping is based in three locations: Rota, Spain; the British Isle of Diego Garcia in the Indian Ocean; and the U.S. Island of Guam in the Western Pacific Ocean. The MPS ships contain nearly everything the Marines need for conducting operations with a 17,000 troop MEB-sized MAGTF for 30 days. The ships do not carry the troops, aircraft, and other smaller pieces of equipment associated with the MEB. Each MPS is a mix of long-term charters and U.S. government-owned vessels crewed by contractor-employed mariners [65].

The Conceptual architecture proposed by the SEA team employs the use of the TSSE ship design in two ways: (1) The Sea Force Ship replaces the LHA in the Naval Expeditionary Strike Group (NESG) operating with legacy assault ship platforms (LPD 17 and LSD 41); (2) The Sea Force ship replaces the legacy assault ship platforms in their entirety—six ships comprise the Sea Base.

From the beginning, the TSSE ship design was envisioned to be an alternative to the LHA(R) concept. The Sea Force ship would operate with an LPD 17 and an LSD 41 as part of an NESG transporting a MEU-sized force. There would be four deployed NESGs strategically positioned in the Mediterranean, Persian Gulf, Indian Ocean, and Western Pacific. These locations would enable the deployed forces to form the Sea Base and begin expeditionary operations within 10 days of a warning order. Only three NESGs would be needed to form the Sea Base. The Conceptual Sea Base with legacy platforms would not be as effective in conducting *STOM* [6] operations. The lift capacity of the Conceptual legacy-mix Sea Base, would not be able to lift the notional MEB defined by this project. At least three of the supply ship variants would need to be prepositioned under this operational concept in the locations currently occupied by the MPF in order to increase the size of the MEB and enhance *STOM* [6] ability.

The Conceptual architecture also proposes a conceptual Sea Base comprised entirely of Sea Force ships. Under this operational concept, the amphibious assault ship components of an NESG would be made up of two Sea Force ships. There would be four deployed NESGs overseas around the same areas described in the "legacy-mix" version of the Conceptual Sea Base. The deployed forces would be able to respond more quickly since the slower, legacy amphibious assault ships are removed from the force structure; the deployed forces would be able to form the Sea Base within eight days of a warning order. Three NESGs would still be needed to form the Sea Base—a total of six Sea Force ships. The all Sea Force ship Sea Base would be fully capable of lifting the notional MEB defined in this report as well as effectively execute a *STOM* [6] operation without the need for prepositioned support shipping. The Sea Base could

conduct expeditionary operations for 30 days without substantial resupply.

Assuming an operation would need to occur in Burma, the legacy-mix Sea Base could arrive on scene and conduct expeditionary operations within ten days of a warning order, but prepositioned shipping would be needed to enhance the size of the MEB and improve *STOM* [6] capability. The all-Sea-Force-ship Sea Base, however, would be able to begin expeditionary operations within eight days of a warning order with no extra support needed from prepositioned shipping for upwards of 30 days. The advantage of the all-Sea-Force-ship Sea Base is that prepositioned shipping would not be needed to enhance *STOM* or lift capability—the six Sea Force ships are fully capable of achieving both requirements.

The distance from San Diego to the southern coast of Burma is about 7, 300 NM [66]. If supply ship variants are used to resupply the Sea Base from CONUS, the supply ships could steam from San Diego to the Sea Base in about 13 days with a 25 knot cruising speed—well within the 30 days of supply that the Sea Base carries. Therefore, the all-Sea-Force-ship Sea Base implies that prepositioned shipping would not be needed.

The current MPF consists of about 16 ships [65]. The current MPF cannot operate as a Sea Base, it must offload all of its equipment at a friendly harbor, and it cannot carry aircraft and troops. If this entire force structure could be replaced with a total of six supply ship Sea Force ship variants (three for SURFLANTFLT; three for SURFPACFLT) it could represent a cost savings while still achieving improved capabilities in the areas of Sea Basing, *STOM*, and logistics support. The all-Sea-Force-ship Conceptual architecture, employing the supply ship variant as described, could also serve as an insurance policy in case

the U.S. is denied the use of its forward, prepositioning bases by diplomatic or military means.

E. IMPACT ON THE CURRENT ARG/NESG COMPOSITION

The impact of Sea Force on the current ARG/NESG composition should be a positive improvement over the existing architecture. Sea Force was design with the intent that it could be used as a LHA replacement and also as a sea basing platform. Sea Force should be able to fill the need for a larger ship necessitated by the procurement of the MV-22 and the Marine Corps desire to conduct Ship to Objective Maneuver (STOM). Due to Sea Force's large size advantage over the current LHA, which has a displacement of about 40,000 LT compared to the 87,000 LT of Sea Force, an ARG/NESG will be able to deploy with more than the standard 15 day loadout. Our estimates show that the loadout can be brought closer to 30 days by exchanging an LHA for a Sea Force ship.

Later on, when it becomes necessary to begin replacing the smaller ships of the ARG/NESG a second Sea Force can replace the two/three smaller amphib's. This would be advantageous because now the loadout for the ARG/NESG can be brought to a full 30 days, and the group will be fully capable of conducting (STOM). Another advantage of an ARG/NESG consisting of two Sea Force ships is that it can carry a third of a MEB and only requires that two similarly composed ARG/NESG's be brought together to form a sea base.

F. AMPHIBIOUS OPERATIONS

1. Surface Craft Management

Although STOM implies that much of the equipment needed ashore will be flown from ship to shore, surface craft will continue to play a major role in amphibious operations. Heavy tracked vehicles such as the M-1A1 Tank are too heavy to be transported by any ship-based aircraft, and must be taken ashore by surface craft. The primary small surface craft that are involved in amphibious warfare are the LCU (Landing Craft) and the LCAC (Landing Craft Air Cushion). The Sea Force is designed to operate with these two craft.

a. LCU's

The LCU 2000 was designed to transport 350 tons of cargo (vehicles, personnel, containers, etc.) from ship to shore at a maximum speed of 12 kts. It has a bow ramp for loading and unloading Roll-on/Roll-off cargo, a bow thruster to assist in beaching and beach extraction and a range of 6,500 NM loaded.

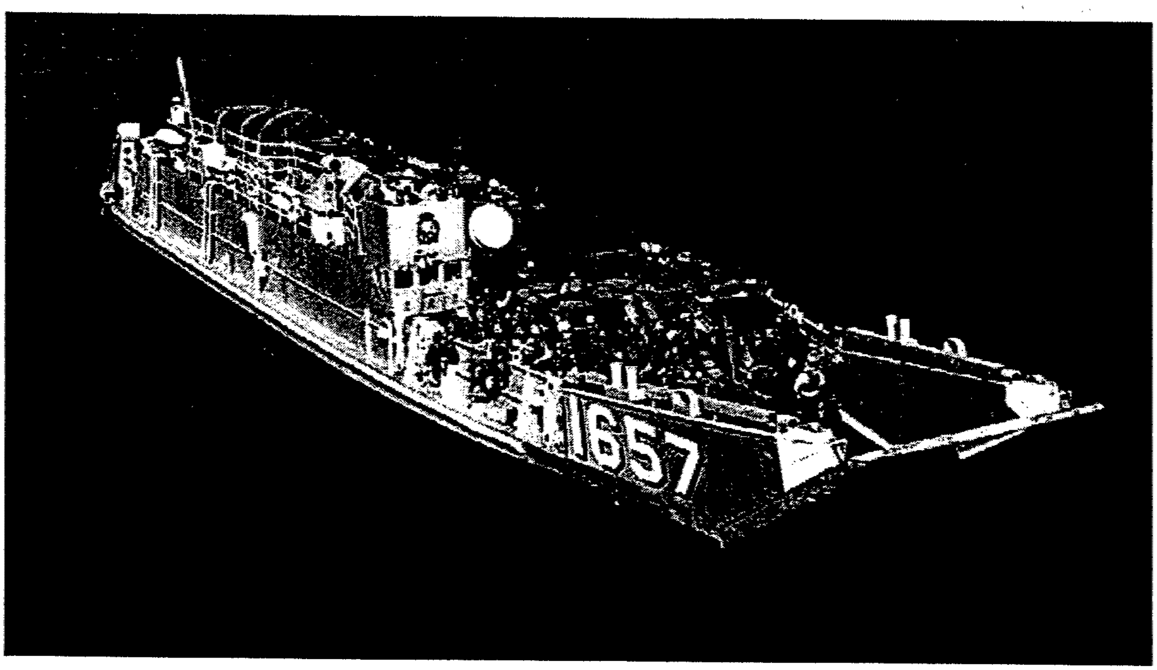


Figure 72. Loaded LCU

b. LCACs

The landing craft air cushion (LCAC) is a high-speed, over-the-beach fully amphibious landing craft capable of carrying a 60-75 ton payload at 40 kts, with a 200-300 mile range. The air cushion allows this vehicle to reach more than 70 percent of the world's coastline and drive up onto the shore, while conventional landing craft can land at only 15 percent of the coasts.

Both the LCU and the LCAC are able to take cargo between ship and shore, and they can also handle ship-to-ship transfers between any two ships that have well decks. The Sea Force is designed to carry 3 LCAC (or two of the planned LCAC replacement, the "LCAC-heavy") and 2 LCUs. The LCACs operate out of the well deck, located in the stern of the ship. This well deck is dry, and thus the LCUs are not able to enter. Instead, LCUs operate in two spots, one between each of the side hulls and the main hull. Equipment transfer for the LCUs is done with a Trolley-rail interface, a system that is currently being researched by the Navy.

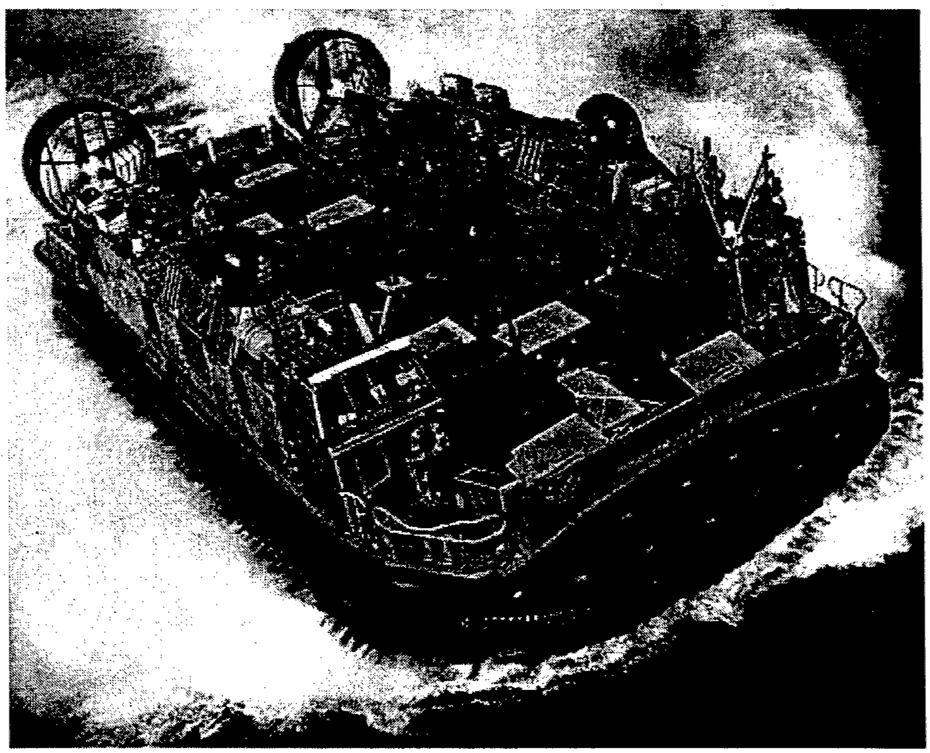


Figure 73. Loaded LCAC

In transit, the 3 LCACs/2LCAC-heavys are stored in the well deck. The LCUs are stored in the superstructure, next to the aircraft hangar. When needed, they are lowered down between the hull with motored winches that have an extremely high gear ratio. They are raised with the same winches, and secured into their storage spaces. This arrangement keeps all surface craft protected from the elements, and they can be accessed for maintenance without launching them.

With this compliment of surface craft, the sea force has a very flexible ability to transfer vehicles and supplies ashore by sea. The LCAC is fast, and the LCU carries a large payload. This compliments the ship's ability to support STOM and sea basing.

2. Flight Deck and Aircraft Management

One of the most important capabilities of the Sea Base is to deploy, support, and sustain the warfighters ashore. Having the means to get "the right stuff, to the right place, at the right time" is critical in order to carry out *Ship-to-Objective Maneuver*. Moving large quantities of logistical supplies over the horizon from the Sea Base to 200 nm inland requires a large dependence on air assets and a large enough Sea Base to support those air assets.

a. Flight Deck Operations

For the assault phase, let us assume that a total of 10,460 troops, which includes the Ground Combat Element (GCE), the Combat Service Support Element (CSSE), and the Command Element (CE) will be participate in the assault. That is perhaps the worst case scenario for a MEB force. Furthermore, we will assume that 16 MV-22s and 12 (2 per ship) of the 24 of the Heavy Lift Aircraft (HLA) will transport troops; the other 12 will be assigned to support the troops by transporting fuel, water, provisions, and extra ammunition. In that way, each ship has a transport capacity of 480 personnel per sortie. To execute the assault, it will require 3.6 sorties of 16 MV-22 and 12 HLA per ship to transport the required 10, 460 personnel ashore. Assuming that every wave takes approximately 4 hours to complete (including reloading and refueling of the aircraft), the entire assault will take little over 14 hours to accomplish (14.4 hours).

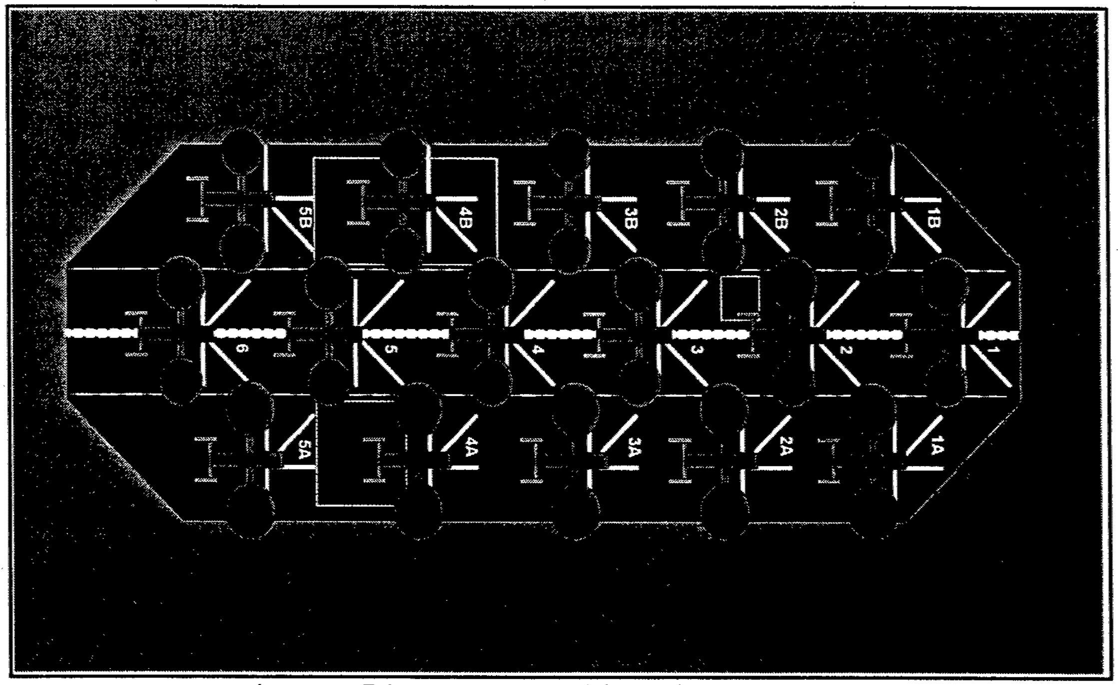


Figure 74. MV-22 Flight Deck Arrangement during Surge Operations

c. Aerial Throughput of the Sea Base

To scope the problem, the throughput in this study examines the short tons per day of daily supply requirements that air assets are capable of delivering. Table 41 shows the daily requirements (tons per day) required to sustain a MEB size Landing Force.

14.97	189.89	225.01	33.48	26.54	489.89

Table 41. Marine Expeditionary Brigade size Landing Force Daily Re-supply Requirements.

Clearly, the largest burdens imposed on aerial delivery assets are fuel, water, and ammunition. To meet the MOE, we proposed a Heavy Lift Aircraft to complement the MV-22; thereby ensuring daily re-supply requirements could reach their Objective.

1. MV-22 and Heavy Lift Aircraft

As envisioned in operational concept *OMFTS,* and its implementing concept - *STOM, and SBL,* the distance from the Sea Base to the Objective could exceed 225 nm - 25 nm from the Sea Base to the beach and 200 nm inland. As mentioned earlier, the MV-22 will be able to deliver 20,000 pounds of supplies and troops to ranges up to 250 nm and at a speed of 240 knots. The Heavy Lift Aircraft will have the capability to carry an external payload of 37,500 pounds 300 nm from the Sea Base to the Objective, offload its payload, and return to the Sea Base without refueling. Additionally, the Heavy Lift Aircraft will be capable of carrying an internal load of 20,000 pounds for 300 nm, offloading, and returning to the Sea Base without refueling.

In Table 42, we show the percentage of re-supply for air deliveries for a 10-hour flight day utilizing 72 MV-22s and 18 Heavy Lift Aircraft. Conceptual aviation assets consist of 96 MV-22s and 24 Heavy Lift Aircraft; however, the table takes into account operational availabilities for both aircraft. The MV-22 uses an operational availability .75 - 96 times .75 equals 72 Fully Mission Capable (FMC) aircraft. The Heavy Lift Aircraft uses an operational availability of .75 - 24 times .75 equals 18 FMC aircraft. Table 42 shows dramatic improvements at all ranges and combat troops supported. The only situation where the Conceptual aviation assets are not adequate is the re-supply requirement for a full MEB equivalent force ashore at 250 nm.

[redacted]

Portion of Force Supported	Tons Needed short tons	Number of Personnel	250 nm	125 nm	55 nm
Full MEB	*2,235*	*17,800*	*49 percent*	*100 percent*	*172 percent*
MEB less ACE	*848*	*10,460*	*128 percent*	*264 percent*	*454 percent*
MEB less ACE and CE	*785*	*9,660*	*138 percent*	*285 percent*	*490 percent*
Landing Force only	*490*	*6,800*	*221 percent*	*456 percent*	*785 percent*

Table 42. Percent of Re-supply for Conceptual Aviation Assets

(Note: For a Landing Force only, the Conceptual Aviation Assets can meet the daily re-supply requirements by 221%.)

2. Conceptual Aviation Assets at Long-Range

The approach used to calculate throughput at long ranges uses the same methodology as applied in Table 42, but with two differences. First, the ranges of interest were changed to 225, 250, and 275 nm. Having the capability to use the sea as a maneuver space and the ability to strike deep inland enhances the Navy and Marine Corps ability to be first to the fight and first to fight. Second, the speed of the MV-22 with an external load was changed from 180 knots to 167 knots; and speed without a load was changed from 180 knots to 240 knots, both these speed changes provide a more realistic numbers.

The daily re-supply requirement for a MEB size Landing Force (GCE only)of approximately 6,800 personnel is 490 short tons. Comparing the days of supplies to the Conceptual throughput capability provides an excellent planning tool for an operational planner. Having flexibility and throughput capability to move large amounts of supplies to combat troops

ashore helps reduce their footprint, making them more mobile to engage the enemy. Tables 43, 44, and 45 were created to show whether or not the Conceptual aviation assets could delivered 1 DOS, 2 DOS, or 3 DOS within 10, 12, or 14 hours for either an external or internal load. Green means the daily re-supply requirement can be achieved and Red means the daily re-supply requirement cannot be achieved, assuming an operational availability of .75 - (18) Heavy Lift Aircraft and (72) MV-22s. The Conceptual aviation assets have the capability to deliver a one- day re-supply for all three distances with the exception of an external load at 275nm and a 10-hour operating time. The requirement to conduct a two-day re-supply is possible with the exception of external loads at 250 and 275 nm. Additionally, it is possible to conduct a three-day re-supply at 225nm, but not at 250 and 275nm. At 14 hours for 225nm, it is possible to conduct a three-day re-supply for both internal and external loads. At 12 hours for 225nm only the internal load is possible.

225 nm				
Cycle Time	**Payload**	**1 DOS**	**2 DOS**	**3 DOS**
10	**Internal**			
10	**External**			
12	**Internal**			
12	**External**			
14	**Internal**			
14	**External**			

Table 43. Capability Matrix for Conceptual Aviation Assets at 225nm

(Note: Operational Availability = .75 and the payload is all internal or all external, but not both. Green means can achieve daily re-supply requirements; Red means cannot achieve requirements.)

250 nm				
Cycle	**Payload**	**1 DOS**	**2 DOS**	**3 DOS**

Time				
10	Internal	[illegible]	[illegible]	[illegible]
10	External	[illegible]	[illegible]	[illegible]
12	Internal	[illegible]	[illegible]	[illegible]
12	External	[illegible]	[illegible]	[illegible]
14	Internal	[illegible]	[illegible]	[illegible]
14	External	[illegible]	[illegible]	[illegible]

Table 44. Capability Matrix for Conceptual Aviation Assets at 250nm

(Note: Operational Availability = .75 and the payload is all internal or all external, but not both. Green means can achieve daily re-supply requirements; Red means cannot achieve requirements)

275 nm				
Cycle Time	Payload	1 DOS	2 DOS	3 DOS
10	Internal	[illegible]	[illegible]	[illegible]
10	External	[illegible]	[illegible]	[illegible]
12	Internal	[illegible]	[illegible]	[illegible]
12	External	[illegible]	[illegible]	[illegible]
14	Internal	[illegible]	[illegible]	[illegible]
14	External	[illegible]	[illegible]	[illegible]

Table 45. Capability Matrix For Conceptual Aviation Assets at 275nm

(Note: Operational Availability = .75 and the payload is all internal or all external, but not both. Green means can achieve daily re-supply requirements; Red means cannot achieve requirements)

Appendix H represents the total tons delivered per day for both the Heavy Lift Aircraft with an external load and the MV-22 with an internal load. The External Load - Heavy Lift Aircraft and the Internal Load - MV22 provides the greatest throughput capability for all three different operating times, whereas, the Internal Load - Heavy Lift Aircraft and the External Load - MV22 provides the least throughput capability for all three different operating times. The difference between the greatest and the least throughput ranges from 100 to 500 total tons delivered,

depending on the number of aircraft available, distance, and operating time.

This table is very user friendly. First, select the operating time of interest -- 10-hours, 12-hours, or 14-hours. Third, select the number of fully mission capable aircraft. The Conceptual Sea Base has 96 MV-22s and 24 Heavy Lift Aircraft. Typically, not all aircraft are available for daily operations because of scheduled maintenance, unscheduled maintenance, and logistical delays. Fully mission capable aircraft are computed by multiplying the operational availability by the total numbered of aircraft - example 96 times .9 equals 86. The following table represents the fully mission capable aircraft based on the different operational availabilities.

HLA	21	20	19	18	16	15	14	13	12
MV-22	86	81	76	72	67	62	57	52	48

Table 46. Fully Mission Capable Heavy Lift Aircraft and MV-22s

In Appendix H, the light blue vertical column represents the fully mission capable aircraft for the MV-22 with an internal load. The light blue horizontal row represents the fully mission capable aircraft for the Heavy Lift Aircraft with an external load. Fourth, select a distance of interest - 225, 250, or 275 nm. The green horizontal and vertical lines represent the three distances. The highlighted yellow rectangles represent the same distances for both the Heavy Lift Aircraft and the MV-22. Fifth, after selecting the fully mission capable aircraft for both the Heavy Lift and the MV-22 and the distance move horizontally across and vertically down until the two meet. The intersection is the throughput capacity (short tons delivered per day). Table 47 illustrates how to

find the throughput capability for following: Operating Time - 12-hours, 18 Heavy Lift Aircraft with external loads, 72 MV-22s with internal load, and distance from Sea Base to Objective equals 225nm. The total throughput capability equals 1953 short tons. 1953 short tons is approximately four times the daily sustainment requirement (490 short tons) for a MEB size Landing Force. Being able to meet the daily re-supply requirements by almost four times has significant ramifications. First, the Sea Base must be able to surge its personnel, equipment, and supplies ashore quickly. The surge requirements are always greater than the sustainment requirement, so having a capability to surge four times the sustainment is definitely a force enabler. Second, even if attrition and other air tasking deplete the re-supplying air capable assets by 50 percent, the Heavy Lift Aircraft and MV-22 could still carry out its re-supply mission. 12 Heavy Lift Aircraft and 48 MV-22s have the capability to move 1302 short tons of supplies - well above 490

External Load -- Heavy Lift Aircraft

Internal Load -- MV-22		21	20	19	[redacted]	16	15	14	13	12
		225	225	225	[redacted]	225	225	225	225	225
86	225	2307	2254	2202	[redacted]	2044	1992	1939	1887	1834
81	225	2237	2184	2132	[redacted]	1974	1922	1869	1817	1764
76	225	2167	2114	2062	[redacted]	1904	1852	1799	1747	1694
[redacted]						1848	1796	1743	1691	1638
67	225	2041	1988	1936	1883	1778	1726	1673	1621	1568
62	225	1971	1918	1866	1813	1708	1656	1603	1551	1498
57	225	1901	1848	1796	1743	1638	1586	1533	1481	1428
52	225	1831	1778	1726	1673	1568	1516	1463	1411	1358
48	225	1775	1722	1670	1617	1512	1460	1407	1355	1302

Table 47. Heavy Lift Aircraft and MV-22 Throughput at a 12-Hour Operating Time (shorts tons)

short tons. Third, weather was not taken into account in this model, but it could easily be accounted for. If bad weather was to restrict flight operations for a four day period, then the

Conceptual aviation assets could take approximately four days re-supply requirements within 12 hours prior to any bad weather arriving. Having a robust capability provides a lot of flexibility in flight hours per day and re-supply periodicity.

3. Heavy Lift Aircraft Simulation Model

We developed an ARENA™ Heavy Lift Aircraft Model to find the minimum number of Heavy Lift Aircraft required for meeting the daily sustainment requirements for a MEB size Landing Force ashore. The model simulates a Heavy Lift Aircraft carrying an internal or external load at either 225, 250, or 275 nm for a 12-hour flight day. Each Sea Force Ship uses 4 of its 16 spots to conduct flight operations, utilizing two spots forward and two spots aft on either side of the Sea Force Ship. The center flight spots remains clear for Joint Strike Fighters. MREs, ammunition, and spare parts are palletized and transferred to the flight spot when requested via omnidirectional vehicles. Assume the transfer of supplies is a uniform distribution -- two to four minutes. After the cargo is transferred to the Heavy Lift Aircraft, it is loaded internally or externally. The Heavy Lift Aircraft has the capacity to carry eight pallets of any type - MREs, ammunition, or spare parts and other. The quadruple container (QUADCON) can carry two pallets per QUADCON for a total eight pallets per container equivalent. Water and fuel are pumped into 500-gallon bladders for external loads and 800-gallon internal tanks for internal loads. The following table summarizes the internal lift capacity for the Heavy Lift Aircraft.

Internal Lift Capacity of the Heavy Lift Aircraft						
	Short	Pounds	Approx	Weight	Pallets	Carrying

	Tons		Weight of Pallet Pounds	800 Gallon Tank Pounds	or 800 Gallon Tanks Required Per Day	Capacity
MREs	15	30,000	1,000		30	8
Water	190	380,000		6,400	60	3
Fuel	225	450,000		5,440	83	3
Ammo	33.5	67,000	2,500		27	8
Spares and Others	26.5	53,000	2,000		27	8

Note: Water is assumed to be 8lbs per gallon and fuel is assumed to be 6.8lbs per gallon.

Table 48. Internal Lift Capacity of the Heavy Lift Aircraft

The loading and unloading times for internal loads are assumed to be a uniform distribution -- eighteen to twenty-five minutes: whereas, the loading and unloading times for external loads are shorter -- four to six minutes. The Heavy Lift Aircraft can load while refueling, but an additional 20 minutes was allotted to account for unexpected problems and longer refueling times. The travel time from the Sea Base to the Objective depends on the payload and the range. Table 50 shows the travel times as triangular distributions (minimum, most likely, maximum).

External Lift Capacity of the Heavy Lift Aircraft						
	Short Tons	Pounds	Approx Weight	Weight 500	Pallets or 500	Carrying Capacity

			of Pallet Pounds	Gallon Bladders Pounds	Gallon Bladders Required Per Day	
MREs	15	30,000	1,000		30	8
Water	190	380,000		4,000	95	6
Fuel	225	450,000		3,400	133	6
Ammo	33.5	67,000	2,500		27	8
Spares and Others	26.5	53,000	2,000		27	8

Note: Water is assumed to be 8lbs per gallon and fuel is assumed to be 6.8lbs per gallon.

Table 49. External Lift Capacity of the Heavy Lift Aircraft

Range	Sea Base to Objective		Objective to Sea Base
	Internal Load	External Load	
225	(60,61,66)	(67,68,73)	(80,81,86)
250	(67,68,73)	(74,75,80)	(87,88,93)
275	(73,74,79)	(82,83,88)	(93,94,99)

Table 50. Heavy Lift Aircraft Flight Times

Utilizing the process analyzer embedded within the ARENA™ software program, the simulation runs were set to determine the minimum number of Heavy Lift Aircraft. Thirty replications of six individual runs were simulated with the following shown in Table 51.

	Recommended Minimum Number of HLAs	
Distance	Internal	External
225nm	20	13
250nm	20	13
275nm	20	17

Table 51. Minimum Number of Heavy Lift Aircraft to re-supply a MEB

(Note: Base on a 12-Hour Operating Time (Flight Day))

D. FLIGHT DECK OPERATIONS DURING SUSTIANMENT PHASE

For the sustainment phase of the operation, we will assume a .75 aircraft availability. With this availability, there are 72 MV-22s, and 18 HLAs available at any given time to sustain the forces ashore. Using Table VI-H-2-6, we found that with this number and combination of air assets, the Sea Base aircraft are capable of transporting 1651 ST of supplies at a range of 250 nm. Assuming that only 7 MV-22 and 2 HLA aircraft spots are available per ships at any given time, it will take approximately 2 (1.8) cycles of 6 MV-22s and 1 (0.75) cycle of 2 HLAs per ship to transport 1651 ST of supplies to the troops at an objective 250 nm from the Sea Base. Figure 75 illustrates the flight deck during the first cycle of the sustainment operations. As illustrated in the figure, all the aircraft are as close as possible to the aircraft and ordnance elevators. In this manner, the loading of the aircraft by the omnidirectional vehicles will be as expeditious as possible. Because of the high throughput of the Sea Base system and the resulted low number of air cycles, the sustainment sorties can be alternated with JSF and other air assets.

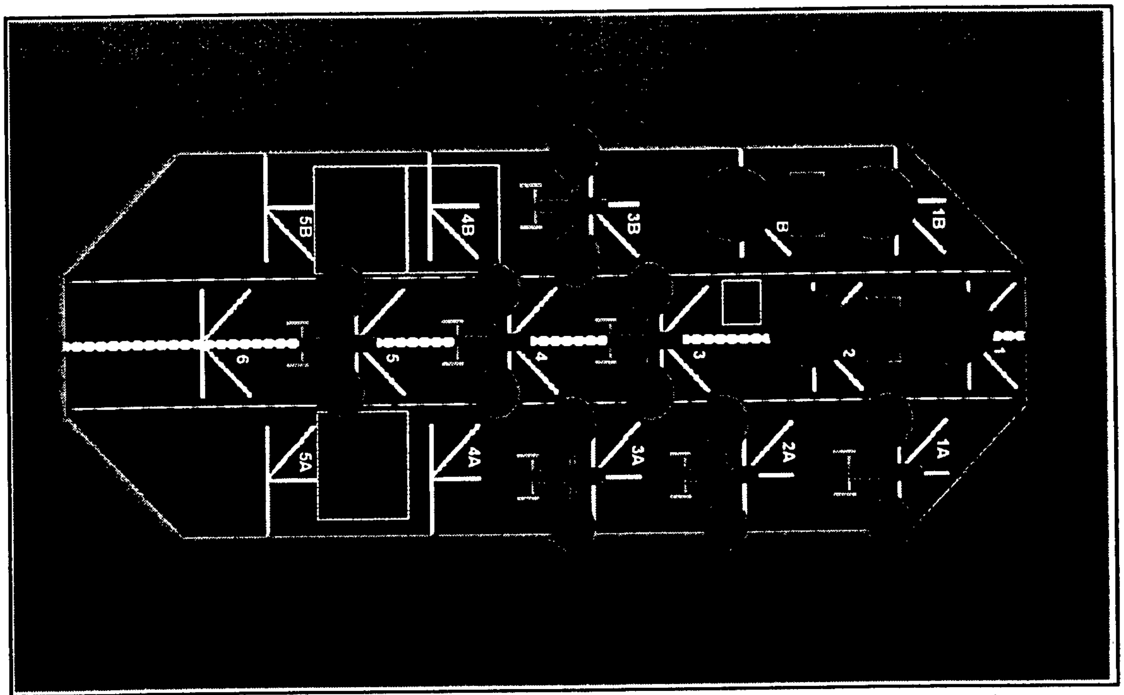


Figure 75. Flight Deck Arrangement during Sustainment Operations

VII. DESIGN EVALUATION

A. REQUIREMENTS THAT WERE NOT FULLY ACHIEVED OR MARGINALLY ACHIEVED

Sea Force fully or marginally met all design requirements. The only requirement marginally achieved was selective offload of vehicles. Due to the self-imposed requirement to operate at a reduced level in a CBR environment the team decided that all aircraft should be able to fit in the hanger bay in a folded status. The Aero heavy-lift aircraft (four) were significantly larger than any other aircraft onboard and storing them in the hanger required a significant portion of the internal volume. In addition to the heavy-lift aircraft the decision was made to store the LCU's internally vice in the welldeck, to avoid the need to add extra ballast for welldeck operations. As a result the vehicle storage areas were impacted to the point that it was not feasible to do completely selective offload of vehicles. What is ment by completely selective is that any vehicle can be taken from its storage location and moved off the ship without requiring the movement of another vehicle. The reason this is mariginally meet is because only a small portion of the vehicles do not meet this requirement, specifically 24 vehicles on the HMMWV/Truck Deck (Main Deck) port side aft.

B. AREAS REQUIRING FURTHER ANALYSIS

1. LCU stowage and loading

The LCU storage area design presents several significant design challenges. The weight of an LCU is in excess of 200 LT and must be lifted in high sea states into its hanger deck stowage area, a minimum of 30 feet. Control of the craft during

the ascent and descent as the ship rolls, as well as, attaching the lifting device will be a driving factor in implementing this portion of the design. Fendering systems, control systems using cables, and motion compensated cranes or wenches were evaluated. Due to time constraints we were not able to further research this area, but do feel that it is possible to design a system capable of accomplishing this task.

Also, further analysis will have to be done on the vehicle ramps for loading and unloading the LCU's between the main and side hulls. The proposed system will be a ramp that attaches to the ship about 15 feet above the waterline. This ramp will provide access to the first vehicle deck in the main hull. The ramp will be design so that relative motion between the LCU and the ship is permitted. Although we know of one master's level thesis on this topic, we do not know of an available ramp that is suited for this application.

Wave height between the main and side hulls will also require further analysis. Under certain conditions it is possible that the wave height could be amplified due to constructive interference between the waves reflected off the main and side hulls. The angle of incidence of the parent wave, wave periodicity, and spacing and shape of the hulls could all contribute to the severity of this problem. Further analysis of sea state trends in desired regions of operation may suggest an optimum spacing or form for the hulls other than that required by naval architecture considerations. It may also be possible to erect a temporary barrier between the two hulls that will act as a breakwater and reduce the wave height to an acceptable operating level. One such system that might have an application in this area would be the Tempest Floating Breakwater by Element

Innovation Inc., which has been demonstrated to reduce wave height by as much as half in a wave tank.

2. Flight deck management and monitoring

The absence of an island on the flight deck has many implications on how flight operations will be conducted if the primary controlling station does not have an unobstructed visual view of the flight deck. The installed deck edge cameras and flight deck sensor grid must be further studied to ensure that data provided to the controller is accurate and presented in a manner that is easily processed by a person. This will also require a large amount of testing and evaluation to prove its reliability and to convince operators that it is safe.

3. Hull

The largest trimaran vessel ever built is the HMS Tritan at 800 LT. The technical issues involved in scaling an 800 LT ship to an 80,000 LT vessel are not clearly understood. Resistance models and hull interactions have not been proven to scale reliably at this size. This can be contributed largely to the fact that there has never been an attempt to build a vessel larger than 800 LT. Another issue for further analysis is the structural members required to tie the three hulls together. The weight penalty imposed by the increased structure may so severely impact the useable payload of the ship that it may make the design impractical.

C. ASSESSMENT OF THE DESIGN

1. Propulsion

The Sea Force will use three big prime movers which are LM 6000 gas turbines and 1 small prime mover which is LM 2500+ to meet the requirement of 30 knots maximum speed and 218 000 hp power. In general, Lm 2500 + is not a small gas turbine for the propulsion or power. But The Sea Force's electrical shipload is 15 MW (20 000 Hp). While at anchor or loitering this power can go up to 20 MW (~27 000 Hp). The LM 2500+ gives maximum power of 29.8 MW. So there won't be so much excess power.

Installing a smaller gas turbine and an emergency also was taken into consideration. Since the ship will not be in the port for long periods, so the emergency gas turbine and the generator was dropped from the consideration.

For the propulsors, as discussed in the previous chapters electrical pods were utilized. The main hull has very limited beam for the location of the pods. So to get rid of this problem and install four pods in an efficient way, new technologies in terms of electrical motors were investigated. Today's technology still isn't meeting our requirements. The electrical motor technology showed great improvement during last twenty years. The electrical motors, used for the propulsion systems, got very compact shapes. Since The Sea Force design had proceeded with the consideration of the technology by year 2020, the team made assumptions for the motor dimensions for the future.

2. Sea state limitations

Under the SEA - IRD document, the ship should be able to operate in at least sea state 3 and should be able to operate/navigate on every sea, ocean everywhere in the world. Although no quantitative sea state analysis was conducted, as there were no available programs to study the sea keeping of tri-hull ships, it is anticipated that the performance of the ship will be better compared with a comparable size ship such as the aircraft carrier based on the much higher righting arm that the Sea Force has over the carrier. Nevertheless, the seaworthiness of the ship may be estimated using the Sea keeping Evaluation Program (SEP) that was developed to evaluate the seaworthiness of SWATH ships. This area would be looked into for the second iteration of the design process.

3. Damage Control

The basic DC system layout was defined including the AFFF, fire main and water mist systems. The manning architecture, however, was not laid out. Manning requirements for the DC system needs to be evaluated and shown. A reduced manning scheme was assumed, but the specific manning was not integrated into the overall layout. To accurately determine the required number of personnel, various scenarios will have to be run to determine the optimal manning structure and the overall effectiveness of the system.

In addition to the firefighting capabilities of the Sea Force, an overall review of the Chemical, Biological and Radiological (CBR) protective measures should be performed.

Water curtains and protective barriers have been defined for use when accessing the well and flight decks, but further study will be required to determine effective and specific access procedures for entering and leaving the ship from other areas. Systems such as the Collective Protection System (CPS) should also be placed on the ship. Once these systems have been integrated into the ship, additional CBR attack scenarios can be run, and performance evaluated. These scenarios, like the firefighting scenarios, can be used to evaluate current and future systems to the overall capability of the Sea Force.

4. Abandon Ship

The ability to safely abandon ship at sea was not designed for or evaluated. The design for this capability should conform to the International Convention for the Safety of Life at Sea (SOLAS) requirements as a baseline. The areas to be analyzed should include the location of the lifeboats and assembly points, the process for accounting of personnel, and the methods of launching the lifeboats based on various ship damage scenarios.

5. Storage Capability and Selective Offload

Operational functionality in the areas of resupply and reconstitution of force is achieved via the well deck, flight deck, LCU decks and motion compensated crane system. The large Flight Deck and internal volume are ideal for supporting STOM, selective off load logistics, and ship to shore logistics. Cargo

and vehicles from any storage area on the ship can be moved to any of these access areas via elevators or ramps. Embarkation of an equivalent cargo payload of 3500LT(188 TEUs) in the warehouse will only utilize 25% of the total warehouse volume allocated in Sea Force. In the supply configured variant, Sea Force trimaran hull form offers volume and the ship is capable of supporting troops ashore without transfer to other ships in the sea base. A volume of 5.7 million cubic feet is available for Containers/Pallets/Ammo on the supply ship through conversion of C4I and combat systems spaces, Marine berthing, and Hangar Bay (to include the LCU storage areas). The original vehicle decks and warehouse spaces are maintained. However, due to the density of containers and cargo that replace the modular spaces in the combat configuration as well as the additional listed areas that are reduced or removed, Sea Force is also weight limited vice volume limited in design. The need to maintain shallow draft for littoral operations may impose weight penalties on the capacity of cargo that the ship is able to transport. Subsequent design iterations may also result in the re-location of the weapons elevator to the side adhering to the hull contour. This will permit simultaneous weapons distribution to the flight deck during STOVL operations and improve the overall logistics flow from handling/storage to loading and delivery to the end-user.

6. Storage Capability and Selective Offloading

Several crucial capabilities are required to enable selective offloading onboard the Sea Force. In terms of volume and space, the ship has sufficient allowance in the warehouse and magazine volume to cater for selective offloading, although subsequent design iterations will need to address a more efficient storage methodology for vehicles.

The influence of automation in cargo handling and tracking systems elaborated in the Chapter on Logistics, greatly facilitates the level of selective off loading capability in the ship. However, in terms of the load handling and movement of equipment within the ship, several enabling technologies such as the Linear Electric Drive, Motion Compensated Crane and the Unified Control Solution (for logistics automation) are incorporated based on existing research and test prototypes which currently remain untested in a dynamic environment onboard the ship.

7. Reconstitution of Forces Ashore

The Sea Force is a Trimaran hull as discussed before. One of the reasons for the Trimaran design was to have enough flight decks to support the air operations and STOM.

To transport the troops and cargo to the shore the MV-22 and CH-53 will be utilized. These aircrafts will also return the injured personnel, damaged vehicles and other equipments from the shore. While these air operations are being conducted the JSF and AH-1 aircraft will protect the marines on shore and will be ready to strike. During embarkation UH-1 aircraft will play the role for command and control and medical evacuation and the UH-60's will be in the theater for search and rescue in case of an accident.

To resupply the troops on shore the distance is the driving factor. The selection of vehicle for transportation depends on the distance and the time. If the reconstitution area is close to the ship the LCACs and LCU can be used. But if the distance from the shore increases it is better to use rotary wings for transportation. In this case the primary type of the aircraft

will be CH-53s and the secondary MV-22. MV-22 can also be used for medical supplies to help UH-1s.

The force deployment will be conducted with LCACs, LCUs and AAAVs. Since the LCUs are dropped to the water from the area between the main hull and side hull, the LCUs and LCACs can start to operate at the same time without causing big problems for the air operations on the flight deck.

8. Manning Concerns

With the budgetary constraints experienced by DoD during the 1990, the Navy leadership started exploring reduced manning onboard ships. In 1995 Admiral Boorda, then Chief of Naval Operations, sponsored the Smart Ship Program to test some of the ideas and technologies that could potentially lead to reduced manning in every ship of the U.S. Navy. In 1995, *USS Yorktown* (CG 48) was the first ship to test this new operational concept. Through the use of a fiber optic Ship Wide Area Network (SWAN), automation software, and a radical change in the ship's organization and watchbill, *Yorktown* successfully operated with an integrated bridge, damage control, and engineering systems which automated many of the routine daily tasks. *Yorktown's* Smart Ship evaluation report also claimed the following:

- A 15% reduction in maintenance workload.
- The potential for an estimated $1.75M per year shipboard manpower savings.
- An estimated $2.76M per year reduction in life cycle costs, including associated shore manpower reductions and shipboard repair savings (US Navy website 2002).

In 1996, a similar program was initiated onboard *USS Rushmore (LSD 47)*. As in the *Yorktown's* case, the *Rushmore* was upgraded with a SWAN and automation software. In addition, *Rushmore* also served as a test platform for new technology to be implemented in the new *San Antonio (LPD 17)* class amphibious assault ships. The increase in automation and efficiency brought about by advanced technologies suggested a consequent reduction in the number of personnel required to operate the ship. Based solely on operational watch standing requirements, it was decided that the ship could reduce its manning from 311 to 268 personnel. The ship would be organized under a core watchbill, with three sections dedicated to standing watch. Non-watch standing personnel would carry out the ship's daily routine, conducting maintenance and keeping the ship clean. These personnel would also be assigned on the core watchbill to billets for infrequent events and special details such as underway replenishment and flight operations. The ship's damage control organization was also revamped, with numbered repair lockers being replaced by the Red, White, and Blue Teams.

As new ships design are developed, reduced manning concepts has increasingly become one of the most import considerations in ship design, not only because it is a fact of life that new automation technologies are becoming more stable and reliable, but also because of its potential benefits in operating cost reductions, quality of life for sailors, and overall ship's readiness.

The following analysis compared manning onboard current amphibious platforms and the proposed manning onboard the TSSE conceptual design. This analysis focuses in manning

demographics, crew volume requirements, and manning costs. This paper ends with sections on conclusions and recommendations.

a. *Manning Demographics*

Analysis Data

Manning demographics and cost data was used from the Naval Center for Cost Analysis. Manning demographics per pay grade for LHA, LHD, LPD, and LSD are illustrated in Appendix I. Manning demographics for the TSSE conceptual design were taken from the TSSE report.

Current Manning

Current manning doctrine onboard Navy ships is heavily composed of junior enlisted personnel, especially between the E-1 through E-3 pay grades. These grades account for 38.6 % of the total crew in a LHA, and for 49 % of the crew in an LPD.

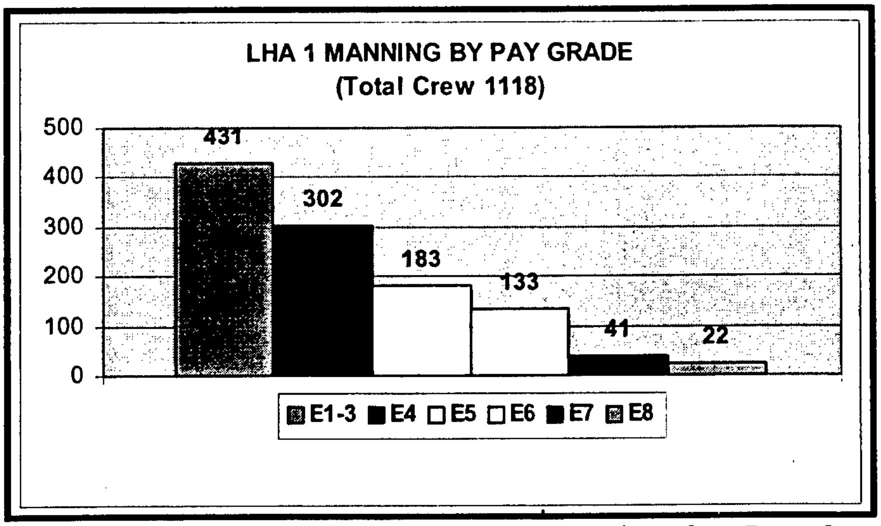


Figure 76. LHA 1 Manning by Pay Grade

In the LHA manning, 277 or 25% of the ship's crew is in a non-designated status. Onboard an LPD, 101 or 26% of the total crew falls into this category. Non-designated personnel are sailors, who, after completing basic training, attended apprentice training in any of four basic areas: Fireman, Airman, Seaman, or Construction Electrician. Personnel in this category have the option of selecting a rate within their basic apprentice area. Personnel between the pay grades of E-1 through E-4 are usually under training in their respective rates. Maintenance performed on equipment by these pay grades is generally restricted to basic Preventive Maintenance System (PMS) maintenance and minor preservation.

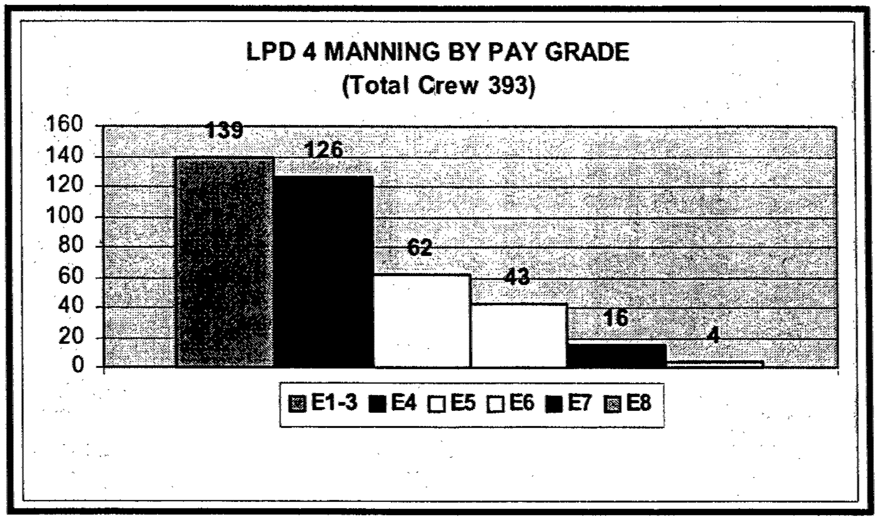


Figure 77. LPD 4 Manning by Pay Grade

The manning by division onboard the LHA is illustrated in Figure 78. In this graph, the main propulsion division (MP) composed of Machinist's Mates (MM) has the highest number of personnel with 88. This illustrates the high manpower requirements for steam propulsion systems. The next largest division is S-2 with 79 personnel. This division is composed mainly of Mess Management Specialist (MS) and Ship's Hotel Serviceman (SH) personnel. The CO Division is composed of the Aviation Ordnance (AO) rate and occupies the third place with 75. This division handles aviation ordnance and maintains the ship's magazines. Divisions in the Air Department follow closely on manpower requirements. From the three division that composed the department, V-1 has the highest number of personnel, followed by V-3 and V-4. Aviation Boatswain's Mates (ABH) make up V-1 and V-3 Divisions, while Aviation Boatswain's Mates Fuels (ABF) compose V-4 Division. Composed of Boatswain's Mates (BM), 1st Division occupies the fourth place with 60 personnel. This division is mostly tasked with the ship's preservation, maintenance and operation of deck equipment and UNREP stations. Repair Division composed mainly by Hull

Technicians (HT), and Damage Controlman (DC) has 47. This division is tasked with repairs of the ship's structure, maintenance and operation of damage control equipment, and are the first line of defense against fires and flooding.

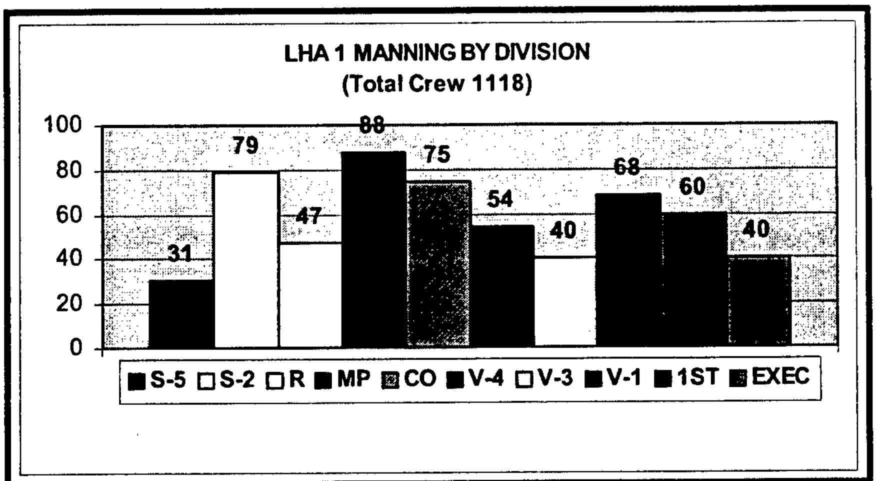


Figure 78. LHA 1 Manning by Division

Figure 79 illustrates the manning by division onboard a LPD 4 class ship. Compared to the LHA the results show a very similar picture of the manning distribution onboard this ship. The main difference between the LPD and LHA manning schemes is that onboard the LPD, 1st Division has the greatest number of personnel with 46, followed by M and B (now MP Division) Division in the Engineering Department with 37 and 34 respectively. The S-2 division in the Supply Department follows closely with 34 personnel.

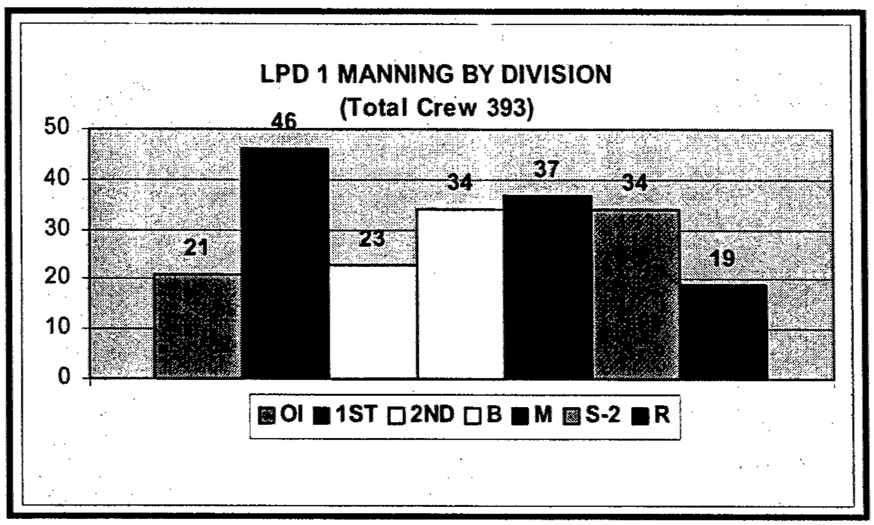


Figure 79. LPD 4 Manning by Division

b. Proposed Manning

In the proposed manning scheme for the TSSE conceptual design, reduced manning was an integral part of the design philosophy. That meant that every system considered to be part of the ship had to address reduced manning requirements. Reduced manning and automation systems were selected especially for Engineering, Supply and logistics support, and Air Departments.

The TSSE conceptual design has a total complement of 724 personnel. Figure 80 shows the breakdown in personnel by pay grade. One of the most drastic changes in the concept's manning was the exclusion of personnel in the pay grades E-1 through E-3.

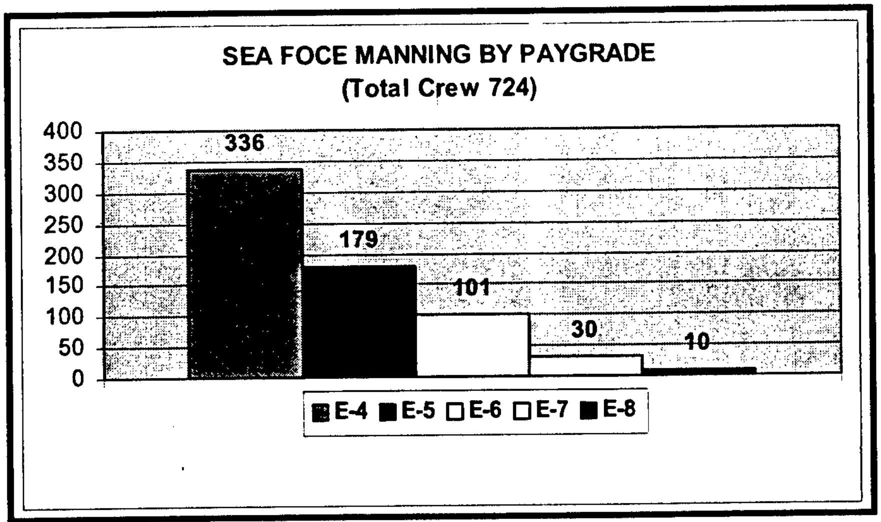


Figure 80. Sea Force Manning by Pay grade

This radical departure from the traditional manning doctrine was made under the assumption that every single sailor reporting to the ship would be fully qualified and trained in his or her watchstation. According to Task Force EXCEL a revolution in personnel training will take place because:

- The complexity of our missions and technologies are growing at an unparalleled rate.
- Over the next several years many of our most experienced people will be retiring.
- Our Sailors expect to learn and grow.
- It is our responsibility to make sure our people are the best trained and most prepared.
- Today, there are extraordinary educational opportunities in the commercial and academic sectors [70].

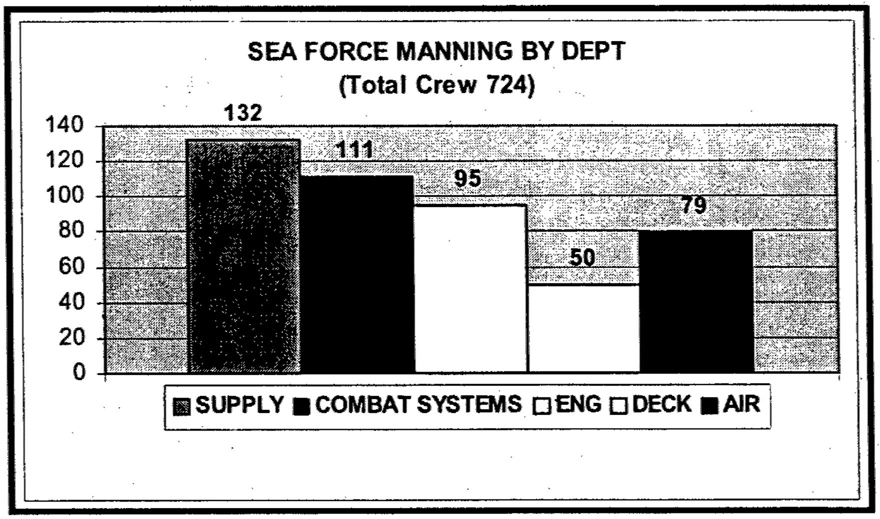


Figure 81. Sea Force Manning by Department

Figure 81 illustrates the TSSE concept design manning by department. Due to the logistic nature of its mission, the supply department has the greatest number of personnel with 132, followed Combat Systems, Engineering and Air Departments with 111, 95, and 79 personnel respectively.

According to the TSSE report, the three departments that made the most use of automation were Supply, Engineering, and Air Departments. These departments also had the greatest decrease in manning. New technologies such as automated store rooms and magazines, electric drive, Integrated Power Distribution (IPS), robotics, and advanced preservation reduced manning in these departments.

CREW VOLUME REQUIREMENTS

Analysis Data

Crew volume requirements data was used from OPNAVINST 9640.1A, Shipboard Habitability Program, section T9640-AB-DDT-010-HAB, Shipboard Habitability Design Criteria Manual. Calculations and data in this manual were used to calculate berthing, head, and messing facilities volumes.

Figure 82 shows the crew volume requirements for each ship class. The LHD has the highest volume requirement with 228,726 ft^3, followed by LHA and TSSE conceptual design with 216,892 and 127, 450 ft^3 respectively. To place these numbers into context, the total cargo capacity for the LHD is 101,000 ft^3 , while the palletized cargo capacity for the LHA is 116, 900 ft^3. The designed warehouse capacity for the TSSE concept design is 819,000 ft^3. In other words, the crew volume requirement for the LHD is 2.26 greater than its effective cargo volume, while the crew volume requirement in an LHA is 1.84 greater than its effective cargo volume. The crew volume requirement for the TSSE conceptual design is only 15.5 % of its total stores cargo capacity.

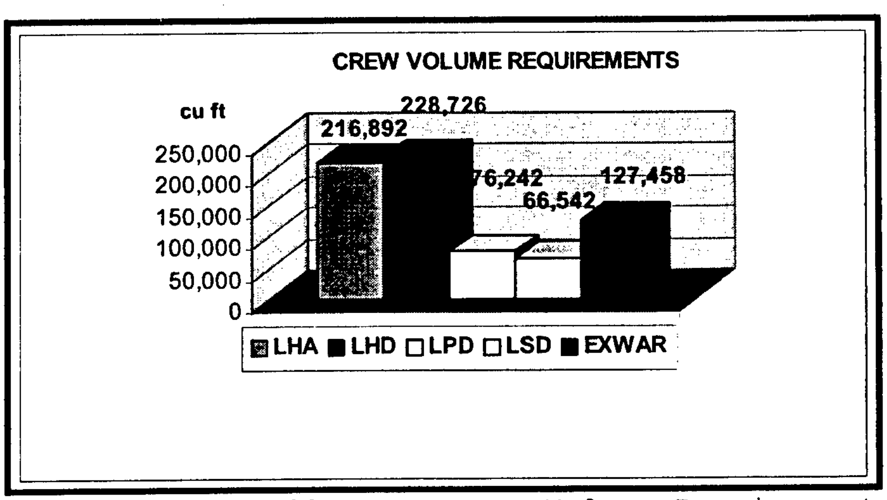
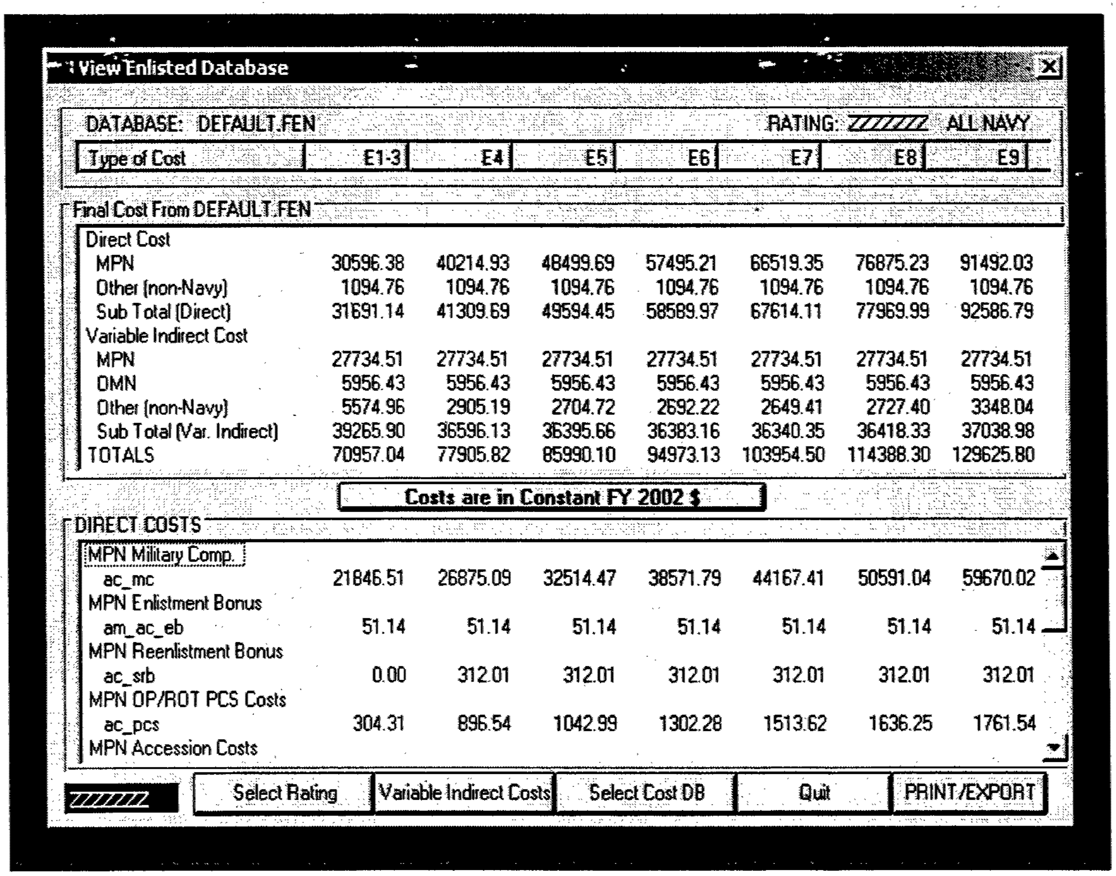


Figure 82. Crew Volume Requirements

MANNING COST

Analysis Data

Manning costs were used from the Cost of Manpower Estimating Tool (COMET) software version 2.0. Figure 83 illustrates the average yearly cost broken down by pay grade. The cost includes direct and variable indirect costs. Direct cost includes items such as military compensation (basic pay), enlistment and reenlistment bonuses etc. Variable indirect costs includes expenditures in training, medical and dental support etc.


View Enlisted Database

DATABASE: DEFAULT.FEN RATING: ZZZZZZZ ALL NAVY

Final Cost From DEFAULT.FEN

Type of Cost	E1-3	E4	E5	E6	E7	E8	E9
Direct Cost							
MPN	30596.38	40214.93	48499.69	57495.21	66519.35	76875.23	91492.03
Other (non-Navy)	1094.76	1094.76	1094.76	1094.76	1094.76	1094.76	1094.76
Sub Total (Direct)	31691.14	41309.69	49594.45	58589.97	67614.11	77969.99	92586.79
Variable Indirect Cost							
MPN	27734.51	27734.51	27734.51	27734.51	27734.51	27734.51	27734.51
OMN	5956.43	5956.43	5956.43	5956.43	5956.43	5956.43	5956.43
Other (non-Navy)	5574.96	2905.19	2704.72	2692.22	2649.41	2727.40	3348.04
Sub Total (Var. Indirect)	39265.90	36596.13	36395.66	36383.16	36340.35	36418.33	37038.98
TOTALS	70957.04	77905.82	85990.10	94973.13	103954.50	114388.30	129625.80

Costs are in Constant FY 2002 $

DIRECT COSTS

MPN Military Comp.							
ac_mc	21846.51	26875.09	32514.47	38571.79	44167.41	50591.04	59670.02
MPN Enlistment Bonus							
am_ac_eb	51.14	51.14	51.14	51.14	51.14	51.14	51.14
MPN Reenlistment Bonus							
ac_srb	0.00	312.01	312.01	312.01	312.01	312.01	312.01
MPN OP/ROT PCS Costs							
ac_pcs	304.31	896.54	1042.99	1302.28	1513.62	1636.25	1761.54
MPN Accession Costs							

ZZZZZZZ Select Rating Variable Indirect Costs Select Cost DB Quit PRINT/EXPORT

Figure 83. Yearly Enlisted Expenditures (2002) (Source: Naval Center for Cost Analysis. Cost of Manpower Estimating Tool COMET Version 2.0)

Manning cost estimates were calculated for the year 2002 , and illustrated in Figure 84. The yearly manning cost for the LHD and the LHA are \$95.3 and \$90 million respectively. The manning cost for the TSSE concept deign is \$55.5 million, while the LPD and the LSD are \$31.6 and \$27.6 million in that order. Despite the fact that the TSSE design displaces over 80,000 long tons, twice the LHA and LHD displacements, reduced manning allows it to operate at \$35.5 million less than the LHA and \$40 million than the LHD.

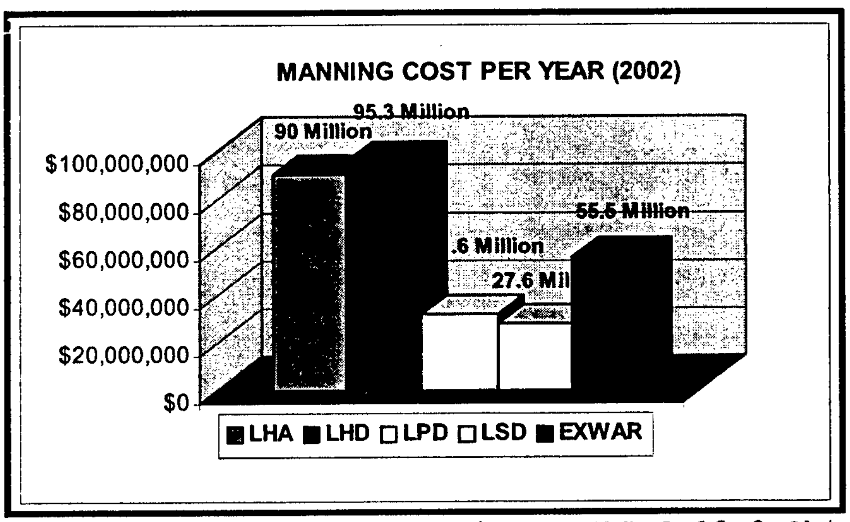


Figure 84. Figure VII-C-12-9 Ship Manning Cost per Year

Figure 85 shows the yearly manning cost of a TSSE conceptual Sea Base composed of six ships, and the yearly manning cost for an afloat Marine Expeditionary Brigade (MEB) composed of 3 LHAs, 3 LHDs , 4 LPDs, and 5 LSDs. The manning cost for an aggregated force of 15 ships is considerably larger

than the manning cost of the conceptual Sea Base. In fact, the manning price tag for the conceptual Sea Base is only 40.6 % of the manning cost of an actual afloat MEB.

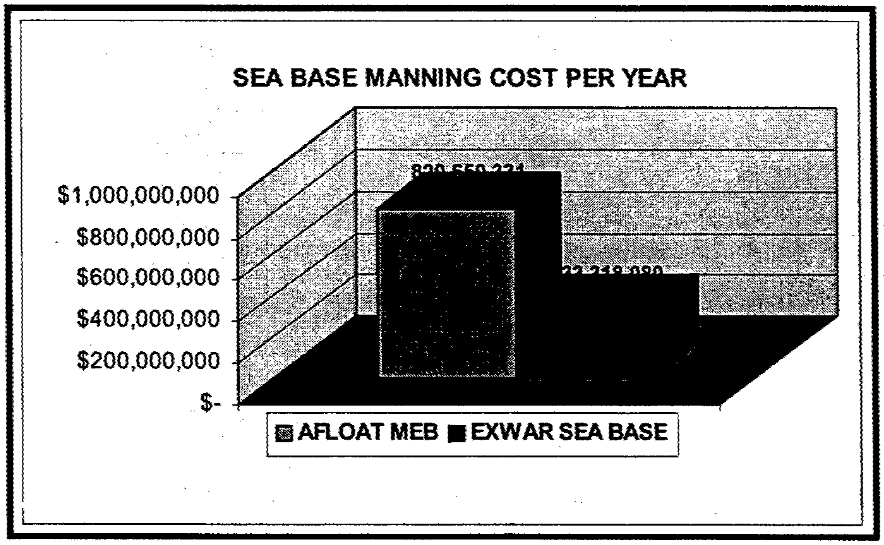


Figure 85. Sea Force Sea Base vs. Afloat MEB Manning Cost

CONCLUSIONS

Reduced manning initiatives have been explored in the U.S. Navy for less than ten years. Only two ships in the Navy, the *USS Yorktown (CG 48)* and the *USS Rushmore (LSD 47)* have implemented this new concept. With only a manning reduction of 10 % and reports that software conflicts left the ships dead in the water [69], the Navy claims a total success in the case of the *Yorktown*. In the case of the *Rushmore*, Cedrik Pringle's Naval Postgraduate School thesis evaluated the impact of the Smart Gator concept on the mission readiness of the *Rushmore*, and concluded that the reduction in manpower and the additional

training requirements for the crew negatively impacted mission readiness [72].

It is a fact, as current manning doctrine shows, that on average close to 50 % of amphibious ships crew is relatively junior, inexperienced and their absence would not prevent the ships from getting underway and operate in an efficient manner. Could we get rid of every single E-1 through E-3 aboard these ships? The answer is because ships like *Yorktown, Rushmore* and the rest of the fleet were not design for reduced manning.

In order for reduce manning to work, it has to be an integral part of the ship's design philosophy. Reduce manning and automation systems, along with new manning doctrines can work, but they have to be planned, integrated, and implemented from conception. Reduced manning will not come easy. Software research is barely scratching the surface of key technologies such as Expert Systems (ES), Decision Support Systems (DSS), and Artificial Intelligence (AI). In addition, reduced manning has tremendous implications for the Navy in areas such as recruitment, training, and retention. Finally, there is institutional resistance that will oppose reduced manning every step of the way.

RECOMMENDATIONS

Are there any benefits to reduced manning? Yes, there are benefits in operational costs, decreased volume requirements, increased performance, and efficiency. Should we attempt to implement it as soon as possible? There is still a long and arduous road ahead, and as mentioned earlier, the process has to be a calculated and progressive one. We have to start with our people. In order to implement reduced manning the Navy will

require to train sailors to make them smarter, technologically savvy, and technically proficient. With this philosophy, the benefits of a smarter workforce will start paying off way before we fully implement reduce manning.

We need to explore every opportunity, process, task, and ask the question…could we make this happen without human intervention? If the answer is yes, how this change will affect combat effectiveness and performance? What type of technology or doctrinal change will help us make it happen?

Finally, technology insertion is not as bad as the media publicized the Yorktown glitches. As a matter of fact, it will be a painful and challenging step towards reduced manning. We need to take a closer look to our most intensive manpower tasks, and ask the questions previously stated. Departments such as Engineering, Supply, and Air are opportunity rich.

9. Cost Optimization

While any design process includes iterations that take into account cost, this exercise was unlimited in that it did not have any restrictions. The design team understands that any major design project of this nature would have had severe cost limitations that impact every aspect of the design. If there were cost restrictions imposed on the design, the team anticipates that a smaller, less structurally magnificent platform would have evolved. The platform would possibly have had a reduced combat systems capability with less pulse power requirements meaning fewer rail guns or fewer FELs. With this being said, one must also admit that with cost restrictions, the design team would have proposed a final design very similar to that of a present day LHD. The final design that did evolve presents a viable solution to the unanswered question of sea basing and STOM.

10. Number of Ships Required

Two criteria drove the system design towards six ships. First, and most important, there was a minimum flight deck area required to conduct STOM operations as defined by the SEA team. Analysis was conducted to determine the amount of transport aircraft that would be needed to move troops and equipment of the MEB a distance of 250 NM in a 24-hour period using 4 sorties per aircraft. Assuming some of the heavier equipment (i.e. MIAI tanks, AAAVs, etc) would still have to be transported via sealift assets, the remaining MEB equipment and troop order could be delivered ashore meeting the requirements and constraints previously described with the aircraft listed in Table 52.

Air Elements	Per Ship	Spot Factor Spread	Total Flight Deck Area	Spot Factor Folded	Total Hangar Bay Area
Aero Design	4	10,530	42,120	5,400	21,600
UH-1Y	4	2,477	9,908	642	2,567
MV-22	16	5,085	81,365	1,532	24,509

Table 52. Transport Aircraft and Associated Area Requirements

Although an underlying assumption was that at least one Carrier Strike Group would be supporting the expeditionary operation, the MEB forces ashore and transport aircraft enroute to the objective still required additional force protection and fire

support. As a result, combat aviation assets (most notably the JSF) were included as part of the notional MEB. These aviation assets are shown in Table 53.

Air Elements	Per Ship	Spot Factor Spread	Total Flight Deck Area	Spot Factor Folded	Total Hangar Bay Area
Aero Design	4	10,530	42,120	5,400	21,600
AH-1Z	4	2,477	9,908	573	2,291
SH-60 F	4	2,477	9,908	642	2,567
MV-22	16	5,085	81,365	1,532	24,509
STOVL JSF	6	1,056	6,334	1,056	6,334
UAV	2	110	220	110	220

Table 53. Combat Aviation Assets and Associated Area Requirements

This analysis demonstrates that a minimum amount of flight deck area was needed to support these aviation assets as well as conduct simultaneous fixed wing and rotary operations in support of a *STOM* expeditionary operation.

Second there was requirement for enough space and volume to support MEB equipment. Analysis was done to determine the weight and volume requirement for all vehicles and supplies required to support a MEB for 30 days.

Analysis showed that the optimum number of ships required having enough flight deck area for STOM and enough internal volume and space to support a MEB is 6.

Reducing the number of ships to complete the same mission will lead to increased displacement, higher than that of a carrier. This is one of criteria that were set earlier in the design process. A larger number of smaller ships would drive up acquisition costs, which is also bad. Efficiency wise, we could

not see a benefit if the number of ships were to increase, because there would be more ships to maintain, more propulsion plants and a larger number of Navy crew that would be doing the same job that our fleet of six ships could do.

11. Future Technology Impact

The Sea Force concept emerged from an evaluation of the present day requirements for Amphibious Warfare and the envisioned requirements for STOM and OMFTS. It allows US Naval Expeditionary forces to command any littoral environment in the world indefinitely without the need for friendly ports. It combines the functions of several ships and incorporates them into one incredibly capable platform. This jump in capability, however, is only as successful as the new technology that will be available to support it. The integral aspects of the Sea Force design that contribute to its ability to achieve STOM and indefinite sustainment include its large flight deck, new aircraft, trimaran hullform that incorporates two waterborne exit points, and its warehousing capability.

The most important realization that the design team had was that a large flight deck would be the driving factor in the ship's ability to achieve STOM. Without a potential airfield, nearly all of the assets on the ship that had to be at the objective, including personnel had to be flown in. The present day methods, while reliable yet slow, force the build-up of equipment and personnel on the beach. The success of the Sea Force concept is dependent on the design of a capable MV-22 aircraft and a new heavy lift helicopter. These two aircraft, combined with the advanced landing craft designs of the HLCAC and LCU(R), would permit successful transfer of supplies, equipment, and personnel to an objective in a rapid manner. The

flight deck design does not incorporate a tower for control and coordination or safety issues. This choice, while radical and uncharacteristic of any large deck aviation capable platform, provides greater stability, greater flexibility in take-off and landing, and allows for automation or reduced manning concepts.

The second area incorporating advanced technology is in the trimaran hull from. The choice was made to use a trimaran in order to support the large flight deck required for STOM. This choice was a major change from traditional naval ship designs and will require significant research in the areas of resistance calculations, structural performance in terms of hull stress and strength, and maintenance.

The Sea Force Combat Systems design incorporates several conceptual technologies that will make this ship the most robust amphibious platform in the fleet. The combination of a Rail Gun and FEL would produce warfare capabilities and doctrine never seen before. While not completely explored, the C4ISR architecture envisioned will permit communications and coordination of battle group assets, shore stations, and autonomous technology unparalleled by anything in the fleet today.

Finally, there are several technologies incorporated in the Sea Force design that are in the test and evaluation phase such as the automated DC-ARM, ammunition warehouse and cargo warehouse areas, and the motion compensated crane. These systems give Sea Force the required capabilities needed to meet sustainment requirements, survivability requirements, and storage requirements with the reduced manning demands of the future.

APPENDIX A

MASTER LIST OF REQUIRED OPERATIONAL CAPABILITIES*

Requirements for our Replacement Ship

Professor Calvano's AIM :
Review and understand the requirements from the SEI team for Sea basing within expeditionary warfare. Further, you must analyze the nature of the requirements and anticipated solutions for the three ship types mentioned above. The goal is to determine if the EXWAR Sea basing requirements can be fully met by a single ship design (with variants permitted) that can be employed in lieu of the separate ship types.

TSSE Team Leader's AIM :
Reviewing the SEI IRD and gaining additional insight as to implications of the requirements given in the SEI IRD
Provide a list of requirements that will meet the SEI IRD
Each team shoul also make a recommendation as to the type and number of ships required to meet these requirement.

AW - Air Warfare

1. Must be able to defend against Advanced anti-ship cruise missiles (ASCM, like the sunburn missile) (LHA CONOPS pg 78)
2. Support the Marine Corps TAMD (seabased Theater Air Missile Defense).
3. Must be able to support and leverage joint integrated air defense systems to provide support throughout the AOA.
4. Will not be expected to be a long-range air defense platform.
5. Ship should have decoy systems designed for an amphibious assault ship.
6. Electronic Warfare suite should be able to facilitate "soft kill" of air threats.

]

AMW - Amphibious Warfare

7. Transport 1700 troops.
8. 300 ft well-deck (to support 3 LCACs, 2 LCUs, AAV, AAAV and future LCU and LCAC replacements advanced amphibious assault vehicles)
9. 2 Deck elevators (LHA/LHD elevators lift 75,000 lbs.)
10. Amphibious operations will be conducted over-the-horizon. Once enemy forces are rolled back, ships can move up and ship-to-shore transfers can take place.
11. The Marine Corps onboard sustainment policy will not change, must support an MEU for 15 days or a MEB for 30 days, or a MEF for 60 days.
12. Designed to transport, land and support the landing force (in the areas of mainenance, supply, medical and fire support coordination) as part of a seabase. This includes providing surface craft control, including serving in the PCS, excercising air control and coordination.
13. Provide airspace and surface management throughout the Amphibious Objective Area (AOA) with high density airspace control zone (HIDACZ).
14. Operate with the MV-22, AAAV, STOVL JSF, SH-60R (fixed wing & rotary), with at least 42 multiple points for aircraft spotting. Can operate aircraft and helicopters simultaneously.
15. Forward deployable.
16. Support Marine Corps Advanced Fire Concept-all weather fire support around the clock, in all types of military operations, using wide array of precision and area weapons with improved range, accuracy, and lethality. Must utilize a mix of precision and accurate non-precision munitions. Can be low-volume fire, since it is precision. Reliable on the first round. Both lethal and non-lethal munitions.
17. Support the operation of UAVs, possibly launching as well.
18. Support Operational Maneuver from the Sea Doctrine.
19. Should prepare and package and transport meals to forces ashore.
20. SUW - Anti-Surface Warfare
21. Has a requirement to be able to repel terrorist attacks/boat attack both in port and underway.
22. USW - Anti-Submarine Warfare
23. Employ torpedo decoy.
24. Must be able to support sustained littoral campaigns in a coastal water submarine environment.
25. CCC - Command Control Communications
26. Support the ESG (Expeditionary Sensor Grid)

27. Must be able to receive info from various UAV platforms, with full Tactical Control Systems.
28. Provide tactical, secure voice or data communications (Plan, coordinate and control implementation of OPSEC measures), must be able to communicate with the embassy, the theatre or JTF commander, any SOF forces being flown in, and staffs as far up the chain of command as the SECDEF.
29. Communications systems compatible with tactical command and the control architecture of ATF.
30. Primary Flight Control (PRIFLY) and Flight Deck Control must not only be in constant communication, but both must have total visibility of the deck and it's operations both day and night.
31. Must be able to wage network centric warfare.
32. Joint C4I to allow interoperability.

C2W - Command Control Warfare

33. Electronic Warfare suite should be able to facilitate "soft kill" of air threats.
34. Should complicate the enemy's targeting process.
35. Employ EMCON procedures.

FSO - Fleet Support Operations

36. At least 578 bed hospital/morgue, 6 operating rooms
37. Provide intermediate level aircraft maintenance (Multiple high-hat areas will be required (for maintenance on the V-22, and JSF).
38. Provide organizational level preventive maintenance.
39. Provide organizational level corrective maintenance.
40. Marine Corps combat training will have to be supported.
41. Support forces ashore for supply maintenance, distribution, salvage engineering, patient movement and services.
42. Medical, dental and veterinary logistics.

INT - Intelligence

43. Must be able to receive info from various UAV platforms, with full Tactical Control Systems.
44. Should be able to monitor electronic emissions ashore and from other ships.

LOG - Logistics

45. Must have at least 25,400 square feet of vehicle storage volume, 125,000 cubic feet of cargo storage volume (3087 cubic meters of dry cargo space).
46. Carry at least 1232 tons of aviation fuel (support operation).
47. Meet maritime pre-positioning platforms while they are on their way.
48. Should provide indefinite sustainment serving as a sea base for logistic support.
49. Should integrate operations with joint in theater logistic agencies and transition from sea based logistics support system to a shore based system.
50. Should receive 20 ft equivalences and other packaging configurations from intra or inter theater distribution sources, segregate contents and components into unit level.
51. Capable of providing temperature and humidity control in designated compartments and cargo storage spaces. They will be fully crewed and capable of getting underway within 24 hours.
52. Capable of operating independently to provide strategic sealift capacity in support of the rapid deployment of heavy mechanized Army and Marine Corps combat units on a worldwide basis.
53. Strategic Sealift Ship mission is to transport common-user cargo and military vehicles, including tanks and helicopters, pre-positioned overseas or surged from the United States to support exercises and real-world contingencies. Equipped with self-sufficient Roll-on/Roll-off (RO/RO) and/or Lift-on/Lift-off (LO/LO) facilities for rapid loading, deployment, and offloading.
54. Transfer ammunition, cargo & missiles underway by Standard Tensioned Replenishment Alongside Method (STREAM).
55. Transfer personnel and light freight by highline.
56. Transfer and receive personnel by helicopter.
57. Provide small boat services for transfer of personnel, cargo, weapons, provisions and
58. supplies.
59. Stock, maintain, and issue: (a) Air munitions, (b) Air-launched missiles, (e) Free-fall/guided munitions
60. Provide large laundry services.
61. Provide supply support services.
62. Provide messing facilities.
63. Provide small arms storage area.

64. Provide for proper storage, handling, use, and transfer of hazardous materials.
65. Use ship's cargo rigs to load and discharge break bulk cargo.
66. Provide ship configuration suitable for container loading and discharging by a shore facility (non-self sustaining container ship).
67. Load, stow, transport and discharge outsized and oversized military equipment.

MIW - Mine Interdiction Warfare

68. Support MIW operations, must have facilities and capabilities fully compatible with operating and supporting mine sweeping assets when necessary.
69. Support a "flyaway" version of the Remote Mine-hunting System, SH-60R w/ Airborne MCM (AMCM) kits (hunt and kill), and the ability to embark MCMC staff.
70. Should posses the self-protective measures to manipulate the platform signature, harden the platform for detonation effects, detect avoid neutralize the mines.

MOB - Mobility

71. Speed must be comparable to other Navy surface ships in the timeframe of 2015 and beyond (25-27 knots or more)
72. Not restricted in size by the Panama Canal.
73. Should be able to operate in at least sea-state 3.
74. Range of 10,000 NM
75. Should conduct in theater reconstitution and redeployment without a requirement for extensive material maintenance or a replenishment at a strategic sustainment base.
76. Operate ship's propulsion plant with split plant operations.
77. Counter and control CBR contaminants/agents.
78. Provide damage control security/surveillance.
79. Should operate/navigate on every sea, ocean everywhere in the world.
80. Get underway, moor, anchor and sortie with duty section in a safe manner.
81. Abandon/scuttle ship rapidly.
82. Provide life boat/raft capacity in accordance with unit's allowance.
83. Tow or be towed (towing engine not required).
84. Moor alongside ATF shipping or docks.
85. Operate in a chemically contaminated environment.

MOS - Missions of State

86. must be flag configured to retain the number of flag-configured big-deck amphibious platforms in the fleet.

NCO - Non Combatant Operations

87. Must be able to operate with other military services, government agencies and multinational forces, operating with aircraft, displacement and non-displacement craft, and command/control to coordinate these operations.
88. Requires a robust multi-media capability that is able to produce, at a minimum: leaflets, posters, schedules. Paper to support the effort, and a means to deliver the materials.
89. Areas for physical exercise.

90. Medical, dental and veterinary logistics.) Conduct combat/non-combat SAR operations by surface ships.
91. Recover man overboard.
92. Provide emergency flooding/fire fighting assistance to another unit.
93. Provide disaster assistance.
94. Support/conduct helicopter/boat evacuation of noncombatant personnel as directed by higher authority from areas of civil or international crisis.
95. Provide for embarkation, identification, processing, care, feeding and berthing of evacuees.
96. Provide care, feeding, and berthing of evacuees.
97. Detect oil or hazardous chemical spill, report spills to proper authority, and conduct pollution abatement operations.

General

98. Must support varying ratios of male and female crew, troops and staff.
99. Must be designed to permit rapid reconfiguration to respond to changing threats and missions.
100. Should conduct one mission while preparing for the other mission, which is unrelated and execute both successfully.
101. Capable of providing berthing accommodations for supercargo personnel who maintain loaded equipment and

cargo. Number dependent on ship class and U.S. Coast Guard Certificate of Inspection (COI) limitations.

102. Identify, equip, and maintain appropriate first aid spaces.

103. Provide facilities and personnel for material, mail and passenger handling.

104. Provide stowage and berthing spaces for equipment and personnel during transit.

105. Monitor the health and well being of the crew to ensure that habitability is consistent with approved habitability procedures and standards.

106. Ensure the operation and maintenance of all phases of shipboard environmental protection systems do not create a health hazard and are consistent with other naval directives pertaining to the prevention of pollution of the environment.

APPENDIX B

INITIAL REQUIREMENTS DOCUMENT (IRD)
FOR
TSSE Design Project
Summer and Fall Quarter 2002

15 August, 2002

1. General Description of Operational Capability

Mission Need Statement: The top-level mission need is implied in the OPNAV Tasker (Ser N7/U655631, 12 April 02) stored on the SEI Share Drive. The SEI CONOPS paints a broad picture of Expeditionary Warfare (ExWar) as it might look like by the year 2020. The SEI CONOPS embodies the capabilities of pertinent documents germane to ExWar as outlined by the OPNAV Tasker.

Overall Mission Area: Expeditionary Warfare.

Description of Proposed System: This system is intended to be a platform, or family of platforms, that encapsulates all mission capabilities and meets system level requirements contained in this document.

Definition of Proposed Mission Capabilities:

Amphibious Warfare (AMW) *The system will be used in amphibious operations to transport, land, and support the landing force. The system will support the operational flexibility and rapid operational tempo (OPTEMPO) required by the ExWar force. It will support littoral operations across the spectrum of conflict – from small-scale contingency missions as part of a forward-deployed Amphibious Ready Group (ARG), to forcible entry missions in a major theater war (MTW) as part of a large naval expeditionary force.*

This system must allow the Marine Corps to fully use the capabilities of future systems such as the Advanced Amphibious Assault Vehicle (AAAV), MV-22, Short Take-Off Vertical Landing Joint Strike Fighter (STOVL JSF), CH-53E or replacement, AH-1Z, UH-1Y and Unmanned Aerial Vehicles (UAV), as well as future amphibious assault command and control capabilities. The system will need to be designed to accommodate growth trends and the insertion of new technologies – such as intermodal transfer and

improved underway replenishment capabilities – throughout its service life to avoid built-in obsolescence.

Seabased Logistics The system must provide for the option of indefinite sustainment, by serving as a conduit for logistics support from military/commercial suppliers. The prolonged operations will demand that the Seabase be able to store and maintain the lighterage and cargo transfer platforms. This capability will reduce the ExWar force's footprint on land, eliminate operational pause, and enable the ExWar force to conduct Ship to Objective Maneuver (STOM) and Operational Maneuver From the Sea (OMFTS). By providing a mobile sea base, the U.S. Navy will become the chain link that will provide the capability to conduct joint, coalition, and interagency expeditionary operations.

Should shore basing be required, the Sea-base will possess the flexibility to support the logistics and maintenance efforts ashore. It will be able to safely navigate and access a wide range of ports worldwide. This will include the ability to conduct Roll On/Roll Off and Lift On/Lift Off cargo operations in the majority of worldwide commercial marine cargo terminals as well as over-the-horizon and in-stream cargo operations in unimproved ports

Other Warfare Areas The platform/s of the Sea Base will operate as amphibious strike groups. For a MEB sized force, an escort package of 3 CG, 3 DDG, 3 FFG/DD, 3 SSN, and a squadron of P-3C Update III AIP aircraft will be tasked to support the Sea Base. Additionally, a CVBG will be associated with the Sea Base, although not necessarily under their direct control; however, the platform/s of the Sea Base must retain a self-defense capability for threats that elude these escorts as described below.

Air Warfare (AW) The system must detect, identify, track, and defeat air targets that have been launched without warning or have eluded AW defenses provided by other fleet units (i.e., "leakers").

Surface Warfare (SUW) The system must include the capability of detecting, tracking, and destroying multiple small, high-speed surface craft. In the dense, cluttered, and environmentally complex littoral regions, the system must be also be able to: Detect surface threats to the horizon with its own sensors

Deconflict potentially hostile craft from friendly and neutral shipping direct aircraft conducting SUW Engage surface threats to the ExWar force within the horizon.

Under-Sea Warfare (USW) The system must support both anti-submarine operations and MCM. The design must provide for the control and support of USW helicopters, and the control of unmanned underwater vehicles (UUV). The ship must support MIW assets. This includes: "Lily-pad" support for airborne mine countermeasures helicopters. Short-term hosting of remote mine search capability (i.e., unmanned surface/subsurface vehicles operated from the ship) is needed. Transporting, directing, supplying, and maintaining of shallow water and very shallow water clearance activities from the landing craft that will be embarked on the ship

Strike Warfare (STW) The system must allow coordinating, tasking and supporting strike missions.

Support Naval Special Warfare (NSW) The system must have C3 functions that can support any embarked command, but with special requirements in the areas of secure communications, storage of non-standard ordnance, and support for craft and SEAL Delivery Vehicles (SDV) and Explosive Ordinance Disposal (EOD) Units.

C4ISR Operational Concept and Requirements The Command and Control (C2) architecture must support planning, gaining, and maintaining situational awareness, decision-making, order generation, weapons direction, and ship system monitoring and control with uninterrupted voice, video, and data connectivity. Interoperability, not just compatibility, of C2 systems across the joint/combined/interagency force is required. Sea based C2 must afford commanders the capability to transition to command ashore. Embarked tactical units need large staging areas to brief units of up to 250 personnel. The conduct of STOM by the landing force demands a ship-to-objective architecture, allowing receipt and rapid response to requests for intelligence, operations, or logistic support at distances approximating 200 nautical miles inland. The design should allow for commercial-off-the-shelf (COTS) equipment replacement without major impact or modification.

The C4ISR architecture must address Naval Surface Fire Support (NSFS) by having the communications facilities required for coordinating the employment of mortars, rockets, artillery, air and naval surface fires. The architecture must have the capability to communicate in a network-centric environment with

the force fires coordination center, the fire support coordination center, fire support elements, joint fires elements, or another surface combatant operating in a land attack controlling unit role, from the SACC. All NSFS capabilities must be fully integrated into joint land attack command, control, communications, computers, intelligence, surveillance, reconnaissance, and targeting (C4ISRT) networks.

Information Warfare (IW), Information Operations (IO), Information Dominance (ID), and Command and Control Warfare (C2W) are capabilities that the C4ISR infrastructure must be able to support. The system must be able to collect, process, exploit, and disseminate an uninterrupted flow of information in support of such operations. It must be able to conduct offensive information operations, and the design should incorporate highly integrated sensor assets to exploit the entire spectrum.

2. Threat.

The capabilities of this system, must be based on existing and potential threat environments in which the future ExWar force might be employed. The future ExWar force will be forward-deployed and rapidly deployable in a chaotic international environment. Belligerents, enemies and potential enemies will range from modern well-equipped forces to individual fanatics. The ExWar force may face military forces, para-military forces, terrorists, criminal organizations, drug and contraband traffickers, gangs, and/or mobs. Additionally, there may well be more than one belligerent faction involved in the conflict, compounding the difficulty for the ExWar force.

Many of the scenarios and adversaries could involve large segments of civilian and non-combatant population. Weapons may range from very primitive to highly sophisticated. The ability of almost every potential adversary to obtain and employ modern weapons has greatly increased. The lethality of the weapons has increased while reaction time in which to defend against them has been drastically reduced. The proliferation of weapons of mass destruction and the probability of their employment will add new and critical aspects to the situation facing the future ExWar force. While preparing to meet the various threats posed by governments and individuals, the ExWar force must also be prepared, when directed by the chain-of-command, to react to a full array of natural disasters and human suffering. (Source: SEI CONOPS)

3. Shortcomings of Existing Systems and C4ISR Architectures

- Insufficient interoperability of C2 systems across the joint/combined/interagency force.
- Inability to provide indefinite, continuous C4ISR and logistics support to expeditionary forces.
- Can not rely on foreign governments to provide bases and facilities for U.S./coalition forces in case of regional contingency.
- Aging amphibious assault platforms.
- The lack of a Seabased Logistic C2.
- Inadequate life to execute OMFTS and STOM.
- Inadequate indefinite sustainment capability.

4. System Level Requirements

a. Baseline AMW Requirements.

- System lift capacity of 1.0 Marine Expeditionary Brigade (MEB). A MEB is a reinforced brigade Marine Air Ground Task Force (MAGTF) made up of three Marine Expeditionary Units (MEU), a reinforced battalion sized MAGTF. A MEU consists of 1200 combat troops and their combat support elements for a total complement of 2200 personnel. A MEB can be formed in two ways: an amphibious MEB roughly consists of the combat load onboard the ships of the three MEU sized Amphibious Readiness Groups (ARG) for a total of 14,000 personnel; however, a maritime pre-positioning squadron (MPRON) can deliver additional vehicles, equipment, materials, and supplies to increase the size and firepower of the MEB (an MPF MEB) to 17,000 total personnel, if required. Starting with the merger of at least two MEU sized ARGs, the Expeditionary Warfare system must be capable of delivering an MPF MEB size force directly to the objective via the Sea Base. Baseline equipment load and supply requirements for an MPF MEB sized force are contained in a spreadsheet found on the SEI share drive in the folder marked "Configuration Control."
- Operate at sea 25 to 250 NM from the beach.
- Employ all capabilities in a sea state of at least three (seas 3.5 - 4 ft, period 2 - 7 sec, average length between swells 52 ft, wind to 15 kts).
- The system must be capable of transoceanic transportation. From a pre- positioning location, and under the conditions stated in the standard Indonesian and Burmese scenarios, the system must be able to arrive on station in no less time than the present day forces (threshold) and preferably in one half the transit time required by present day forces (objective).

- Accommodate both current and future aviation and surface assault assets – including helicopters, MV-22, STOVL JSF, AAAV, LCAC, LCU(R), and MCM assets – under improved day or night, adverse weather conditions. The platforms must be compatible with operations of existing and future surface ships such as the LHD and LPD-17. The Sea Base platforms must operate with the long range, heavy lift aircraft conceptual design under development by the Aeronautical Engineering curriculum. The heavy lift design will have a spot factor no greater then twice that of a CH-53E, spread and folded. The design goal is a spot factor 1.5 times that of a CH-53E, spread and folded. The aircraft maximum gross weight is projected to be as high as 110,000 - 140,000 lbs for the quad tilt rotor concept.
- Sea Base platforms required to carry both troops and support materials must be capable of simultaneously spotting, starting, loading, and launching troop transport and heavy lift aircraft. These simultaneous operations must be capable of moving troops and supplies at as least the same rate as individual troop and cargo operations from current platforms. The ability to concurrently operate STOVL fixed wing attack aircraft and troop/material transport aircraft from individual ships of the Sea Base is desired, but not required.
- The platforms must be able to operate unmanned vehicles including Unmanned Aerial Vehicles (UAV), Unmanned Surface Vehicles (USV), and Unmanned Underwater Vehicles (UUV).
- Support training for the crew and embarked units.
- Provide organic battle group and JTF-level scenario development and simulation-based rehearsal capability.
- Support Tactical Recovery of Aircraft and Personnel (TRAP) missions.
- Direct the surface and air assaults; provide surface craft control, including serving as the primary control station; and exercise air control and coordination.
- Interoperability capability in all aspects, including logistics, combat systems, C4ISR etc with other services as well as allied forces.

b. Seabasing and Logistics Requirements.

- The system must act as an integrated OTH, floating distribution center and workshop providing sustainment to a MEB for 30 days, with a throughput ability to sustain the MEB ashore for an indefinite time.

- Provide command and control of logistics operations within the seabase and ashore.
- The system must be able to receive supplies and materials via 8′ x 8′ x 20′ and 8′ x 8′ x 40′ shipping containers as well as 8′ x 8′ x 5′ "quadcons." The system must be capable of moving these stores and supplies within the sea base as well as reconfiguring them onto 48″ x 40″ wooden pallets for transfer ashore, if required.
- The system must be capable of conducting vertical replenishment operations with UH-1Y, MV-22A, CH-53E, and the Aero conceptual design aircraft to support the logistics requirement of the landing force without interrupting aircraft troop transport and surface craft operations.
- *Provide increased aviation ordnance stowage, handling facilities, and equipment to accommodate the wide variety and quantity of air-delivered ordnance associated with the missions and aircraft mix of the ACE.*
- The system design must support reconstitution and redeployment of the ExWar force entirely through the Sea Base.
- Design must possess selective offload capabilities to reinforce the assault echelon of an ExWar force.
- *Spaces (especially cargo spaces) should allow flexibility for easy reconfiguration for multi-mission purposes between stores, facilities, and personnel.*
- The primary role of the Sea Base is the support of operations by expeditionary forces ashore. While the platforms of the Sea Base must be compatible with current and future fleet oilers and supply ships, *a secondary role of supporting escort and Sea Base assets with similar services will be considered prior to the FRD.*

c. Information Exchange Requirements.

- The C4ISR system must have defense-in-depth. To prevent intrusion, the information system and TSCE must be physically protected, firewalled, and redundant.
- Communications and computers must support secure, reliable, network-centric communications and data exchange, not only with the warfare mission commanders, but also with other surface ships, submarines, and manned and unmanned aircraft.
- The system must facilitate reachback to the theater and CONUS facilities for ISR products.

- Provide the embarked staff a C4ISR capability that supports decentralized, naval, network-centric, and joint/combined/interagency operations.

d. Environmental, Safety and Occupational Health (ESOH) and Other System Characteristics.

- Must comply with Federal EPA and NAVOSH regulations and international law as applicable.

5. Program Support.

a. Maintenance Planning.

- The system must have Intermediate Level (I-Level) Maintenance for aircraft, landing craft, other platforms in company and ownself.

b. Human Systems Integration.

- Reduced manning concepts must be employed.
- Ensure crew comfort/QOL.
- Design the system to accommodate mixed genders.

c. Other Logistics and Facilities Considerations.

- *The system must support medical evacuation evolutions, whether from combatant operations or in support of MOOTW and NEO operations. This includes patient regulation, transport/evacuation, receipt, and stabilization in preparation for transport.*
- *The system must be capable of receiving casualties from air and waterborne craft.*
- The system must include adequate treatment facilities for critical patients and decompression facilities for EOD personnel.

6. Program Affordability. TBD

7. References.

For more information read the following:

- OPNAV Tasker (Ser N7/U655631, 12 April 02)
- SEI CONOPS
- The Maritime Vision

- The Naval Operational Concept
- The Maritime Concept
- Expeditionary Maneuver Warfare
- Seabased Logistics, May 1998
- MPF 2010 and Beyond
- STOM CONOPS

APPENDIX C

Parametric Studies to estimate Full Load Displacement of Ships

A parametric study was conducted to estimate the full load displacement of the ships during the Analysis of Alternatives phase. Current ships with capabilities that are similar and of comparable displacement to the design were chosen for the study. These ships include the LHD, LHA, LMSR and the two MPF 2010 designs. Ship's characteristics under considerations were light ship displacement, full load displacement, ship's length, displacement-to-length ratio and speed. For the full load displacement and volume relationship, the issue of concern was that the weight density of compartments are different, however as we are comparing ships of similar functionalities these differences should average themselves out. For the full load displacement and length relationship, the premise lies with the assumption that with similar drive towards a more efficient hull design the length of the ship needs to increase with its displacement. However this relationship is less predictable because there are other parameters that affect the length of the ship being chosen which relates to the displacement of the ship in a different manner. Relationship between displacement and speed were also studied to determine if these could be used as an estimate.

The study showed that the relationship between full load displacement and hull volume has a strong linear relationship. The team decided to use this relationship to estimate the full load displacement of the ships during the Analysis of Alternatives phase. In retrospect, the full load displacement

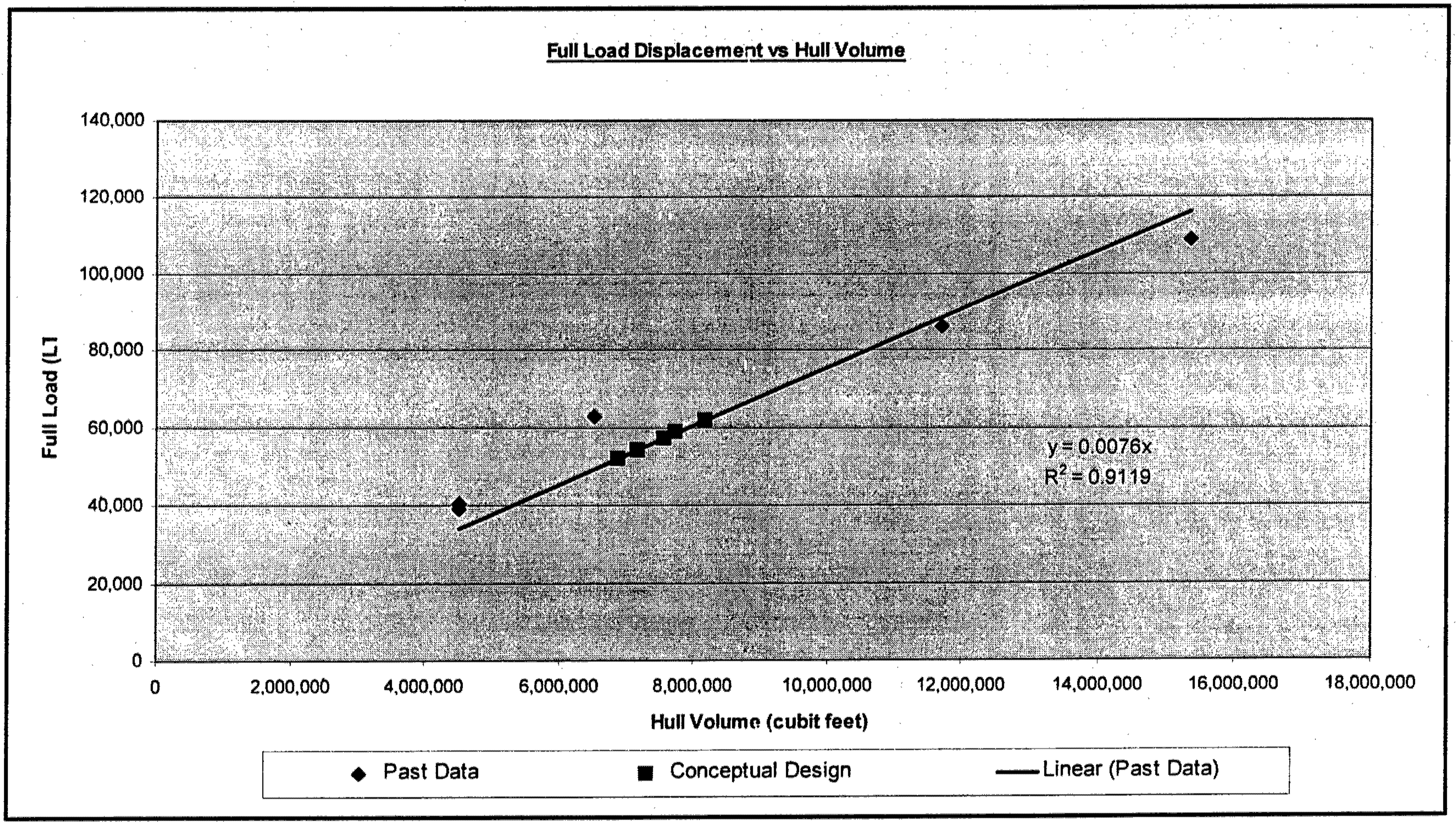
of Sea Force was also estimated based on this relationship and the result corresponds well with the results obtained from Auto hydro.

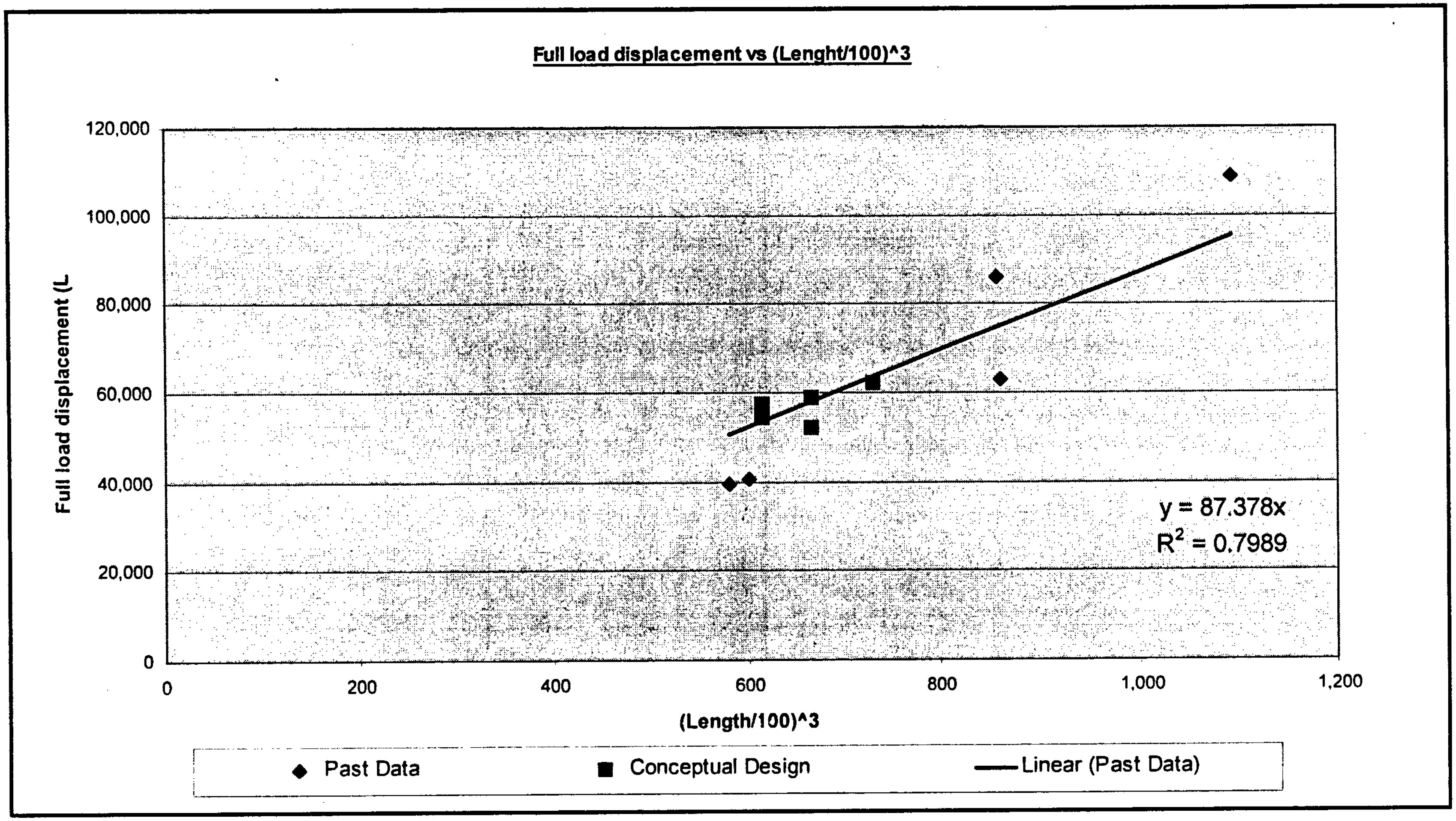
Comparison of characteristics of ships involve in amphibious operations.

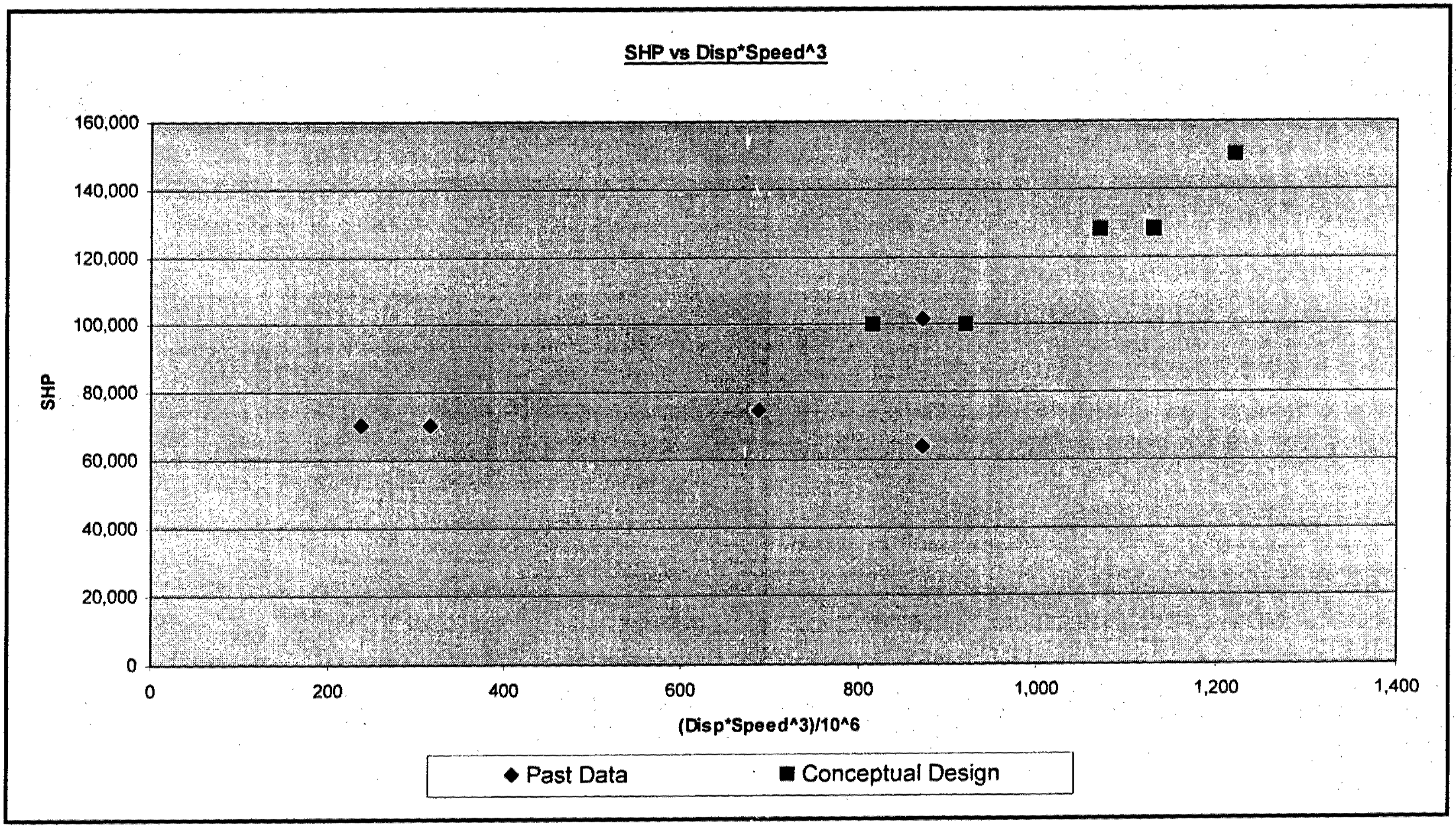
	LHD	LHA	LMSR	MPF 2010 A	MPF 2010 B	K CLASS	C CLASS	LMSR[K]	LHA/MPF[LM]	X CLASS
Lightship	28,250	26,255	55,000	47,950	65,700					
Full Load	40,500	39,400	63,000	85,950	109,000	58,852	52,176	54,403	57,477	62,056 *
Full Load						57,860	57,860	53,452	53,452	63,451 **
Vehicle stowage	20,000	33,730			182,000	57,930	99,460	135,000	50,000	
Volume	101,000	116,900	3,537,000							
Length, L	844	834	951	950	1,030	873	873	850	850	900
(Length/100)^3	601	580	860	857	1,093	665	665	614	614	729
LWL	800	791	901	900	976	827	827	806	806	853
Beam, B	106	106	106	140	150	140	140	140	140	140
Depth, D	67	67	80	106	119	77	71	74	77	78
Draft, T	27	26	30	35	35	30	30	30	30	30
C_B	0.59	0.60	0.73	0.65	0.71	0.56	0.50	0.53	0.56	0.57
Displacement Length	79.10	79.75	86.01	117.72	117.13	103.96	92.16	104.02	109.90	99.96
Volume - Hull	4,496,454	4,503,208	6,520,770	11,689,610	15,377,010	7,743,635	6,865,284	7,158,242	7,562,795	8,165,316
SHP	70,000	70,000	64,000	74,500	101,500	100,000	100,000	128,200	128,200	150,000
Speed - Max	24	24	24	27	27	40	40			
Range	9,500	10,000	12,000	12,000	12,000	10,000	10,000	10,000	10,000	10,000
R-Speed	18	20	24	20	20	25	25	27	27	27
Disp*Speed	729,000	788,000	1,512,000	1,719,000	2,180,000	1,471,291	1,304,404	1,468,871	1,551,886	1,675,523
Disp*Speed^3	236	315	871	688	872	920	815	1,071	1,131	1,221

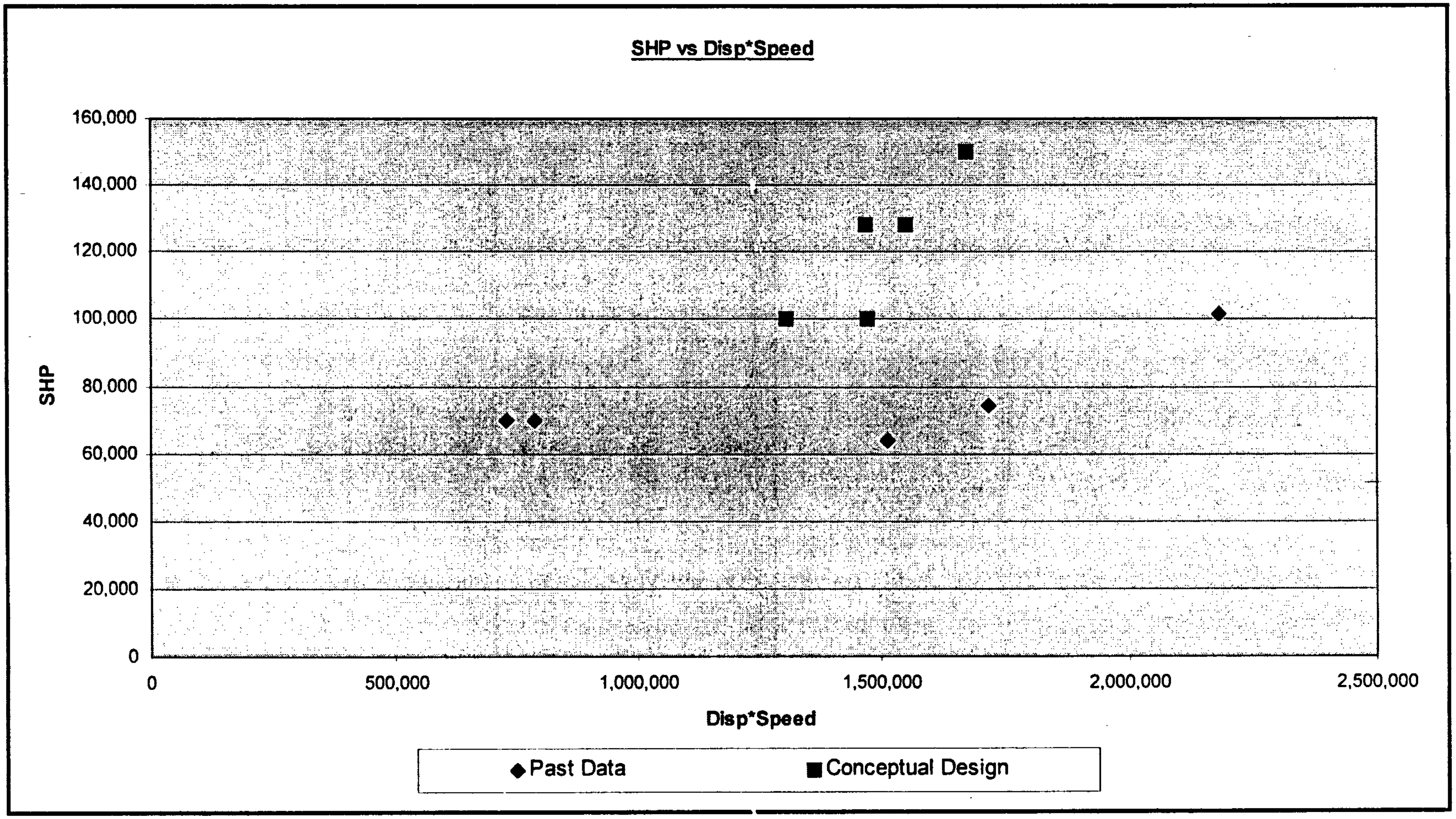
* Based on full load displacement to hull volume relationship

** A check based on full load displacement to ship's length


Full Load Displacement vs Hull Volume
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Full Load (LT
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
14,000,000
16,000,000
18,000,000
Hull Volume (cubit feet)
y = 0.0076x
R2 = 0.9119
Past Data
Conceptual Design
Linear (Past Data)


Full load displacement vs (Lenght/100)^3
120,000
100,000
80,000
60,000
40,000
20,000
0
Full load displacement (L
0
200
400
600
800
1,000
1,200
(Length/100)^3
y = 87.378x
R2 = 0.7989
Past Data
Conceptual Design
Linear (Past Data)


SHP vs Disp*Speed^3
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
SHP
0
200
400
600
800
1,000
1,200
1,400
(Disp*Speed^3)/10^6
◆ Past Data
■ Conceptual Design


SHP vs Disp*Speed
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
SHP
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
Disp*Speed
Past Data
Conceptual Design

APPENDIX D

Load-out for LHA and MPF/LMSR Variant

Table 1. Detailed Loadout of the two variants.

	LHA Variant			MPF/LMSR Variant		
Major Weapons	No.	Weight (LT)	Volume (ft^3)	No.	Weight (LT)	Volume (ft^3)
LAV AT	2	32	6,073	0	0	0
LAV 25	8	127	24,294	0	0	0
LAV LOG	1	16	3,037	0	0	0
LAV RECOV	1	16	3,037	0	0	0
AAAVC7	3	119	29,259	0	0	0
AAAVR7	2	79	19,506	0	0	0
AAAVP7	37	1,469	360,867	0	0	0
M1A1	4	303	29,184	16	1,213	116,736
HMMWV (TOW)	24	73	30,586	0	0	0
M198 How	10	88	70,486	0	0	0
Sub-Total	92	2,323	576,329	16	1,213	116,736

	LHA Variant			MPF/LMSR Variant		
MT/Comm Equipment	No.	Weight (LT)	Volume (ft^3)	No.	Weight (LT)	Volume (ft^3)
Armed HMMWV	19	64	18,160	0	0	0
LVS Power Unit	37	0	0	0	0	0
LVS Wrecker	2	0	10,336	0	0	0
LVS Trailer	18	0	93,024	0	0	0
5 Ton	0	0	0	94	1,130	362,464
P-19 8	3	0	27,972	0	0	0
HMMWV	0	0	0	158	460	201,355
MRC-110	0	0	0	22	0	0
MRC-138	0	0	0	20	0	0
MRC-142	0	0	0	7	0	0
M970 Refueler	0	0	0	9	0	156,060
Sub-Total	79	64	149,492	261	1,590	719,879

	LHA Variant			MPF/LMSR Variant		
Engineer Equipment	No.	Weight (LT)	Volume (ft^3)	No.	Weight (LT)	Volume (ft^3)
ROWPU	0	0	0	14	37	10,216
RTCH	0	0	0	5	327	55,216
D7	0	0	0	6	116	27,289
EBFL	0	0	0	16	0	72,000
TRAM 644E	0	0	0	13	0	58,500
M9 ACE	0	0	0	2	40	3,812
MC1150 Tractor	0	0	0	3	0	4,860
Line Charge	0	0	0	6	0	0
Watercons	0	0	0	37	0	0
Sub-Total	0	0	0	102	521	231,893

	LHA Variant			MPF/LMSR Variant		
Air Elements	No.	Weight (LT)	Volume (ft^3)	No.	Weight (LT)	Volume (ft^3)
CH-53 D/E	8	133	1,702,225	3	50	638,334
AH-1Z	3	15	108,250	1	5	36,083
UH-1Y	3	17	110,726	1	6	36,909
MV-22	8	133	735,673	4	66	367,837
STOVL JSF	6	68	110,849	0	0	0
UAV	2	0	0	1	0	0
Sub-Total	30	365	2,767,723	10	127	1,079,163

	LHA Variant			MPF/LMSR Variant		
Commodity	No.	Weight (LT)	Volume (ft^3)	No.	Weight (LT)	Volume (ft^3)
Provisions		380	64,600		570	96,900
Ordnance		2,475	210,375		3,713	315,563
Fuel		5,316	250,815		7,974	376,223
Aviation Fuel		5,829	256,666		8,743	384,998
Sub-Total		14,000	782,456		20,999	1,173,684

	LHA Variant	MPF/LMSR Variant

	No.	Weight (LT)	Volume (ft^3)	No.	Weight (LT)	Volume (ft^3)
Payload		16,751	4,276,000		24,450	3,476,659
Propulsion & Auxiliary		4,735	500,000			500,000
Fuel		8,898	470,186			470,186
Habitability			535,750			545,000
Combat Systems		1,523	10,000			5,000
C4I			10,000			5,000
Hospital & Medical Facilities			3,000			240,000
Hangar			2,332,600			451,122
Aircraft Maintenance			288,750			0
Aircraft Equipment stowage			126,000			25,200
Well Deck			413,600			827,200
Miscellaneous			254,866			254,866
Total			7,437,796			6,559,445

Table 2. Computation of Volume Requirement of Ship

	LHA Variant (ft^3)	MPF/LMSR Variant (ft^3)
Payload	4,276,000	3,476,659
Propulsion & Auxiliary	500,000	500,000
Fuel	470,186	470,186
Habitability	535,750	545,000
Combat Systems	10,000	5,000
C4I	10,000	5,000
Hospital & Medical Facilities	3,000	240,000
Hangar	2,332,600	451,122
Aircraft Maintenance	288,750	0
Aircraft Equipment stowage	126,000	25,200
Well Deck	413,600	827,200
Miscellaneous	254,866	254,866
Total	7,437,796	6,559,445

APPENDIX E

Functional breakdown of Ship Crew onboard Sea Force.

Category	Billet	Rate/Rank	Watch	Others	Total Watch Requirement
Officers	CO			1	
	XO			1	
	OPS			1	
	Ops Divos			4	
	Suppo			1	
	Sup Divos			4	
	Weaps			1	
	Weaps Divos			2	
	CSO			1	
	CS Divos			1	
	Navigator			1	
	Admin Off.			1	
	Legal Off.			1	
	Cheng			1	
	Eng Divos			4	
	Air Boss			1	
	Mini Boss			1	
	Air Divos			3	
	First LT			1	
	Deck Divos			3	
	AIMD/BFIMA Off			1	
	R-Divos			4	
	SMO			1	
	Medical Divos			8	
	SH-60 Pilot			3	
Senior Enlisted					
	CMC			1	
	Dept. SCPOs			10	
	CPOs			30	
SLQ-32					
	Watch Sup	EW2, EW1	1		4
	MM	EW1, EW2, EW3			
Cooks/Hotel					
		MS1, MS2, MS3	52		52
		SH1, SH2, SH3	40		40

Category	Billet	Rate/Rank	Watch	Others	Total Watch Requirement
Radar					
	RCC	OS2, OS3	1		4
	MM	ET2, ET3			
CIC					
	Sup	OS1	1		4
	Link Control	OS2, OS3	1		4
	NTCS-A	OS2,OS3	1		4
	R/T	OS3, OSSN	1		4
	AIC	OSC, OS1	1		4
TACRON Det					
	Officer			1	
	Sup		1		4
	Operators		2		8
Radio					
	Sup	IT1, IT2	1		4
	OP	IT2, IT3	4		16
	MM	ET1, ET2, ET3			
Combat Systems Repair					
	Sup	ET1, FC1	1		4
	MM	ET2, ET3, FC2, FC3		30	
IMA Repair					
	BFIMA	HT/EN/MM/MR		40	
Flight deck					
	Flight Ops Ctr	Flight Deck Controller	6		24
		Operators	2		8
		radar			
	Plane Crews	Aug. w/MAGTF per.			
	Safety	LSO	1		4
		F/D Sup.	1		4
		Asst. F/D Sup.	1		4
	Maintenance			20	
SH-60 (4)					
	Plane Crews				9

Category	Billet	Rate/Rank	Watch	Others	Total Watch Requirement
	Maintenance				8
Engineering Dept.					
	MMR 1	GME2, GME3	1		4
	MMR 2	GME2, GME3	1		4
	MMR 3	GME2, GME3	1		4
	Oil/Water King	GME1, MM1	1		4
	EMOW	EM1, EM2	1		4
	SWBD/LC Operators	EM3	3		12
	Auxiliaries	EN2, EN3, MM2, MM3	3		12
	DCC	DC2	1		4
	Rover	DC3	2		8
	MM	GME/MM		10	
	Ship Eng. Repair	EM/EN/HT/DC E-6, E-5, E-4		16	
Medical					
	Sup	HM1, DT1	1		4
	Pharmacist	HM2	1		4
	Emergency Rm	HM2	1	12	4
	Corpsmen	HM2, HM3, DT2, DT3		40	
Supply Support					
	Disb. Sup	DK1		1	
	Parts Issue	SK1, SK2	3		12
	Stores	SK2, SK3		30	
Admin/Legal					
	Sup	PN1, LN1, YN1	2		8
	Clerks			5	
Weapons:					
Rail Gun	WCC	GM1	1		4
	LCC	GM2, GM3	1		4
	MM	GM2, GM3		4	
FEL	WCC	FC1	1		4
	LCC	FC2, FC3	1		4
	MM	FC2, FC3		4	
RAM	WCC	FC1,	1		4
	LCC	FC1, FC2, FC3	1		4
	MM	FC1, FC2, FC3		4	
50 cal/small	aug. w/MM				

Category	Billet	Rate/Rank	Watch	Others	Total Watch Requirement
arms					
USW	WCC	TM1, STG1	1		4
	LCC	STG2, STG3	1		4
	MM	TM2, TM3, STG2, STG3		4	
	Ordinance			30	
Deck Dept.					
	Boat Crew	BM2, BM3		5	
	UNREP/Line Handling Stations	BM1, BM2		20	
	Crane Operators	BM1, BM2		5	
	Preservation/Maint	BM3/SN		10	
Navigation					
	Charts	QM1, QM2	1		4
		Sub-total		383	341
		Total = 724			
WCC	Weapons Control Console				
LaCC	Launcher Control Console				
Sup	In charge of space/operation				
DCC	Damage Control Central				
MM	Maintenance Man				
LCC	Local Control Console				
RCC	Radar Control console				

APPENDIX F

COST ESTIMATE

Sea Force Specialized Equipment used for ship cost estimate

Costs are reflected back to 1991 at 3% inflation rate to align with CER's in given model.
Later, total is reflected to 2001 with same inflation rate.

One Time Installs	Costs in 2002	Costs in 1991
Engines/Pods	$100,000,000	$72,242,128
Electric Plant	$60,000,000	$43,345,277
Composite Hull Form	$50,000,000	$36,121,064
EW Suite	$30,000,000	$21,672,638
SPS-73 Radar	$500,000	$361,211
Volume Search Radar	$50,000,000	$36,121,064
Free Electron Laser	$55,000,000	$39,733,170
Other Weps/Sensor Systems	$20,000,000	$14,448,426
Rail Gun	$100,000,000	$72,242,128
SEA RAM	$30,000,000	$21,672,638
Automated DC systs.	$35,000,000	$25,284,745
DC Automation IP (.75*gear)	$26,250,000	$18,963,559
Automated Flight Deck/Hanger	$5,000,000	$3,612,106
Automated Weapons Handling	$35,000,000	$25,284,745
Automated Warehouse System	$30,000,000	$21,672,638
Network Centric CMD/CONT.	$300,000,000	$216,726,383
SUMS	$596,750,000	$669,503,918

Airwing Costs

Concept	# per ship	Cost per unit	Total Cost
HLA	4	65	260
AH-1Z	4	14	56
UH-1Y	4	14	56
MV-22	16	57	912
JSF	6	50	300
SH-60F	4	20.25	81
Costs are in FY02 million dollars			1,665

TSSE Sea Force Cost Estimate

Description		WT (LT)	Wt/Tot	Other	Sea Force MAT CER	Sea Force MATERIAL COSTS	Sea Force Labor CER	Sea Force Labor Hours
Ref Tot.	71381	86000						
SHELL + SUPPORTS		6106	0.08554		1181	$7,211,186	316	1929496
HULL STRUCTURAL BULKHEADS		8084	0.11325		1181	$9,547,204	316	2554544
HULL DECKS		8342	0.11687		1181	$9,851,902	316	2636072
HULL PLATFORMS/FLATS		1118	0.01566		1181	$1,320,358	316	353288
DECK HOUSE STRUCTURE		2924	0.04096		1028	$3,005,872	692	2023408
SPECIAL STRUCTURES		10234	0.14337		1632	$16,701,888	251	2568734
MASTS+KINGPOSTS+SERV PLATFORM		411.94	0.00577		6183	$2,547,025	164	67558
FOUNDATIONS		1462	0.02048		1028	$1,502,936	359	524858
SPECIAL PURPOSE SYSTEMS		1548	0.02169	100000000	4758	$107,365,384	404	625392
Structure Sum		40229.9	0.56359			$159,053,755		13283350
PROPULSION UNITS		1032	0.01446		144	$148,608	209	215688
TRANSMISSION+PROPULSIOR SYSTEMS		200.38	0.00281		63	$12,624	162	32462
SUPPORT SYSTEMS		524.6	0.00735		288	$151,085	412	216135
PROPUL SUP SYS -FUEL,LUBE OIL		77.4	0.00108		36916	$2,857,298	1412	109289
SPECIAL PURPOSE SYSTEMS		55.04	0.00077		288	$15,852	0	0
Propulsion Sum		1889.4	0.02647			$3,185,467		573574
ELECTRIC POWER GENERATION		430	0.00602		650	$279,500	4	1720
POWER DIST. SYSTEM		1497.26	0.02098		98329	$147,224,079	1294	1937454
LIGHTING SYSTEM		362.92	0.00508		5450	$1,977,914	1329	482321
POWER GEN SUPPT. SYSTEM		184.9	0.00259		14545	$2,689,371	1882	347982
SPECIAL PURPOSE SYSTEMS		61.06	0.00086		788	$48,115	471	28759
Electrical Sum		2536.1	0.03553			$152,218,978		2798236
COMMAND+CONTROL SYS		81.7	0.00114	8000000	150000	$20,255,000	235	19200
NAVIGATION SYS		51.6	0.00072		150000	$7,740,000	235	12126
INTERIOR COMMS		150.5	0.00211		150000	$22,575,000	235	35368
EXTERIOR COMMS		123.84	0.00173		150000	$18,576,000	235	29102
SURF SURV SYS (RADAR)		215	0.00301	5000000	150000	$37,250,000	235	50525
COUNTERMEASURES		10.922	0.00015		150000	$1,638,300	235	2567
FIRE CONTROL SYS		68.8	0.00096		150000	$10,320,000	235	16168
SPECIAL PURPOSE SYS		36.12	0.00051		150000	$5,418,000	235	8488
Command/Cont Sum		738.5	0.01035			$123,772,300		173543
CLIMATE CONTROL		1125.74	0.01577		32868	$37,000,822	494	556116
SEA WATER SYSTEMS		688	0.00964		50705	$34,885,040	679	467152
FRESH WATER SYSTEMS		140.18	0.00196		34033	$4,770,746	529	74155
FUELS/LUBRICANTS, HANDLING+STORAGE		1681.3	0.02355		42125	$70,824,763	271	455632
AIR, GAS+MISC FLUID SYSTEM		208.98	0.00293		70265	$14,683,980	647	135210
SHIP CONTL SYS		0	0.00000		14025	$0	353	0
UNDERWAY REPLENISHMENT SYSTMES		1806.86	0.02531		8035	$14,518,120	176	318007

	(3% inflation rate)			Total 2002 Material Cost	$1,320,487,433
SHIPS FORCE		359.48	0.00504		
MISSION RELATED EXPENDABLES		1931.56	0.02706		
STORES		811.84	0.01137		
LIQUIDS, PETROLEUM BASED		23306	0.32650		
LIQUIDS, NON-PETROLEUM BASED		783.46	0.01098		
FUTURE GROWTH MARGIN		546.1	0.00765	**Payload Cost**	
Total Payload weight:		27738.44	0.38860	**$13,869,220**	
	Check Sums	90684.2	1.1		

Ship assembly and support labor = .478*Labor		10963732.4	
Integration and Engineering Labor = .186*Labor		4266222.22	
Program Management Labor = .194*Labor		4449715.65	**(4th ship) Labor cost**
Combined Labor Total Hours @ rate	30	42616348.8	**$1,278,490,465**

	Hours		Labor Cost	Multi-Hull Adj .30*Labor
Total 1997 1st Ship Labor	47220331.1	1st Ship	$1,416,609,933	$424,982,980
Total 1997 2nd Ship Labor	44859314.55	2nd Ship	$1,345,779,436	$403,733,831
Total 1997 3rd Ship Labor	43533318.85	3rd Ship	$1,305,999,565	$391,799,870
Total 1997 4th Ship Labor	42616348.82	4th Ship	**$1,278,490,465**	**$383,547,139**
Total 1997 5th Ship Labor	41918413.87	5th Ship	$1,257,552,416	$377,265,725
Total 1997 6th Ship Labor	41356652.9	6th Ship	$1,240,699,587	$372,209,876
Total 1997 7th Ship Labor	40887568.21	7th Ship	$1,226,627,046	$367,988,114
Total 1997 8th Ship Labor	40485531.38	8th Ship	$1,214,565,941	$364,369,782
Total 1997 9th Ship Labor	40134192.32	9th Ship	$1,204,025,770	$361,207,731

Shipyard Overhead Tabulation		
Shipyard Gen. & Admin O.H.	0.065	
Shipyard Insurance	0.01	
Shipyard Contingency	0.1	
Shipyard Profit	0.04	
Total Shipyard O.H. Rate	0.215	
Engineering Burdened Rate	$50.00	
Non-Recurring Engineering Hours	10000000	$500,000,000
Navy Program Cost Factor = 1%		$5,000,000
Total Non-recurring Eng. Cost		$505,000,000
	0.95	
Learning Curve Exponent		

Unit cost with basic Shipyard Overhead	With Multi-Hull Labor Overhead		
$3,325,573,300	$3,750,556,280	1st Ship W/Eng Burden	$4,255,556,280
$3,239,514,246	$3,643,248,077		
$3,191,181,703	$3,582,981,573		
$3,157,758,146	**$3,541,305,285**	**<------Acquisition Cost**	
$3,132,318,417	$3,509,584,141		
$3,111,842,229	$3,484,052,106	(Fourth Ship)	
$3,094,744,092	$3,462,732,206	Estimated System Cost (w/o Manning):	
$3,080,089,850	$3,444,459,632	**Ship**	**$3,541,305,285**
$3,067,283,541	$3,428,491,272	One Time Installs	$596,750,000
		Payload	$13,869,220
		Sail Away Cost	$4,151,924,505
		airwing (A/C):	$1,665,000,000
		Total System Cost	$5,816,924,505

APPENDIX G

Load-out of Notional Marine Expeditionary Brigade

Major Weapons	MEB	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
LAV AT	4	14.20	56.80	20.97	8.83	8.20	6073.42
LAV 25	14	14.20	198.80	20.97	8.83	8.20	21256.95
LAV LOG	3	14.20	42.60	20.97	8.83	8.20	4555.06
LAV RECOV	3	14.20	42.60	20.97	8.83	8.20	4555.06
AAAVC7	9	35.45	319.05	38.80	11.97	10.50	43889.20
AAAVR7	4	35.45	141.80	38.80	11.97	10.50	19506.31
AAAVP7	96	35.45	3403.20	38.80	11.97	10.50	468151.49
M1A1	58	67.70	3926.60	32.00	12.00	9.50	211584.00
Armed HMMWV (TOW)	72	2.70	194.40	15.00	7.08	6.00	45878.40
M198 How	30	7.88	236.40	40.50	9.16	9.50	105729.30
[redacted]			[redacted]				[redacted]

MT/Comm Equipment	MEB	Weight per unit (ST)	Total Weight (ST)	L (ft)	W ft)	H (ft)	Total Vol (ft^3)
Armed HMMWV	57	3.00	171.00	15.00	7.08	4.50	27240.30
LVS Power Unit	109	12.65	1378.85	19.90	8.00	8.50	147498.80
LVS Wrecker	4	14.20	56.80	20.70	8.00	11.50	7617.60
LVS Trailer	53	8.00	424.00	19.90	8.00	4.20	35437.92
5 Ton	282	10.73	3025.86	25.00	8.00	9.64	543696.00
P-19	8	16.80	134.40	27.10	8.00	10.00	17344.00
HMMWV	473	2.60	1229.80	15.00	7.08	6.00	301395.60
MRC-110	65	2.60	169.00	15.00	7.08	6.00	41418.00
MRC-138	60	2.60	156.00	15.00	7.08	6.00	38232.00
MRC-142	21	2.60	54.60	15.00	7.08	6.00	13381.20
M970 Refueler	26	7.65	198.90	30.50	8.10	8.75	56203.88
[redacted]			[redacted]				[redacted]

Combat Eng./Eng. Support	MEB	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
ROWPU	41	2.33	95.53	9.48	6.91	5.57	14959.79
RTCH	14	58.48	818.72	35.19	11.64	13.48	77301.90
D7	17	17.29	293.93	30.50	8.00	9.32	38659.36
Extension Boom Forklift	46	13.00	598.00	20.40	8.10	9.70	73730.09
TRAM	37	16.70	617.90	22.25	8.70	11.00	78785.03
M9 ACE	6	18.00	108.00	20.49	10.50	8.86	11437.11
MC1150 Tractor	7	13.90	97.30	16.30	6.80	9.50	7370.86
Line Charge	18		0.00				0.00
Watercons	111	1.35	149.85	6.50	8.00	4.00	23088.00
***Other (p. 123-124)**			1389.60				162666.00
[redacted]			[redacted]				[redacted]

Expeditionary Airfield	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
CONTAINER	304		6,508	20.0	8.5	8.0	389,120
[illegible]			[illegible]				[illegible]

Offload Control Unit	MEB	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
TRK HMMWV	13	2.6	34	15.0	7.1	6.1	8,403
AMBULANCE	2	2.6	5	15.0	7.2	6.0	1,290
LARC	4	9.5	38	35.5	10.4	10.4	15,408
TRK 5T DUMP	1	11.9	12	23.0	8.0	10.5	1,932
TRK 5T CARGO	6	11.3	68	27.7	8.0	8.3	11,067
TRK 5T TRKTR	2	10.1	20	22.1	8.2	7.9	2,855
TRK GEN PURP	2	8.3	17	23.7	8.0	9.3	3,534
WRECKER 5T	1	18.0	18	30.3	8.2	8.8	2,182
TRK TANK GP	2	5.3	11	21.5	8.0	8.5	2,924
TRLR 1 1/2T	2	1.3	3	13.5	8.0	4.8	1,044
LOWBED 50T	2	8.7	17	38.3	8.0	6.3	3,876
400G WTR TRLR	6	1.4	8	13.5	6.8	7.0	3,827
F/L 4K LB	2	6.0	12	13.8	6.7	5.8	1,069
F/L 16K LB	2	13.8	28	24.0	8.4	8.0	3,232
COMPRESSOR	3	2.7	8	12.9	7.8	5.9	1,777
SCOOP LOADER	2	11.9	24	28.0	8.0	10.7	4,779
TRC CRLR 195 HP	4	26.5	106	20.0	12.3	11.1	10,936
FLOODLIGHT	8	1.3	10	13.3	5.8	5.1	3,163
GEN 5KW	2	0.5	1	4.3	2.7	3.1	71
GEN 10KW	10	0.6	6	5.2	2.7	3.1	425
GEN 30KW	10	1.4	14	6.7	3.0	4.6	917
WELDING MACH	6	1.6	10	13.1	6.2	6.2	2,985
PUMP (ROWPU)	8	0.1	1	2.5	2.0	2.5	100
PUMP,CENTRIF	4	0.8	3	10.7	5.0	4.3	924
CLEANER,STEAM	2	0.3	1	5.3	2.8	3.7	106
ROWPU	2	4.4	9	9.6	7.0	5.7	760
REEFER CONT	2	3.9	8	20.0	8.0	8.0	2,560
LAUNDRY UNIT	2	2.5	5	9.5	7.0	7.0	931
CRANE 30T	1	28.6	29	40.4	8.0	11.7	3,772

LCM-8	8	67.0	536	73.7	21.0	17.0	210,392
CIN	14	75.0	1,050	83.8	21.3	5.2	128,859
CBE	16	75.0	1,200	88.3	21.3	5.2	155,026
SLWT	5	103.0	515	83.8	21.3	13.8	123,218
CSP	16	98.0	1,568	89.8	21.3	13.8	422,516
[illegible]			[illegible]				[illegible]

Mobile Const. Battalion	**MPF,E**	**Weight per unit (ST)**	**Total Weight (ST)**	**L (ft)**	**W (ft)**	**H (ft)**	**Total Vol (ft^3)**
TRK CARG 8500	1	2.6	2.6	15.0	7.2	6.1	654
TRK CAR M998A1	11	2.6	28.8	15.0	7.2	6.0	7,095
TRK CARG 8500(ARMT)	11	3.3	36.3	15.0	7.2	5.5	6,504
TRK CARG 10000	6	3.0	17.7	15.9	7.2	6.0	4,107
TRK CARG 10000	4	3.0	11.8	15.9	7.2	6.0	2,738
TRK AMB M1035A1	2	2.6	5.3	15.0	7.2	6.0	1,290
TRK 5T DUMP MIL	2	12.0	23.9	22.9	8.0	10.1	3,697
TRK CRGO 5T MIL	7	11.1	77.6	26.3	8.0	9.7	14,210
TRK 15T STAKE	7	9.8	68.4	29.2	8.0	8.7	14,156
TRK DUMP 46000	14	8.5	119.0	23.4	8.0	9.5	24,915
TRK 15T TRACTOR	13	8.0	104.3	24.2	8.0	8.7	21,782
TRK TRAC 60000	7	6.2	43.7	25.0	8.0	10.3	14,350
TRK FIELD SERV	2	8.3	16.6	23.7	8.0	9.3	3,534
TRK MAINT UTIL	4	3.1	12.2	17.9	6.6	6.5	3,067
TRK WRECKER 25T	2	0.0	0.0	29.2	8.0	8.6	4,006
TRK TNK FUEL	2	7.1	14.2	21.9	8.0	8.3	2,922
SEMI STAKE 34T	10	0.0	0.0	40.0	8.0	4.7	14,933
SEMI LOWBED 35T	13	6.6	86.2	38.6	8.0	6.3	25,079
DOLLY TRLR CONV	5	1.4	6.8	9.0	8.0	4.2	1,500
TRLR TNK 400G	11	1.4	15.0	13.5	6.8	7.0	7,017
TRFK D 4LB PRT	4	6.0	23.9	13.8	6.7	5.8	2,139
TRFK D 12LB PRT	6	13.8	82.5	24.0	8.4	8.0	9,696
TRFK D 50LB PRT	2	53.4	106.8	37.2	20.0	16.2	24,034
MXR CONC 11CF	3	2.5	7.4	10.2	7.8	9.2	2,167
DISTRIB ASPHALT	1	0.0	0.0	30.9	9.2	8.7	2,456
DISTRIB WATER	3	10.9	32.7	27.7	8.0	8.7	5,755
DISTRIB WATER	2	35.5	71.0	51.0	10.3	11.8	12,285
COMPRES 250 CFM	4	1.7	6.6	14.0	6.3	5.5	1,951
CPMPRES 750 CFM	1	4.6	4.6	16.2	7.3	7.7	909
COMPRES 750 CFM	1	6.7	6.7	21.8	7.4	8.5	1,376

Mobile Const. Battalion	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
AUGER EARTH	2	12.0	24.0	27.3	8.0	10.6	4,614
DRILL WELL 1500	1	0.0	0.0	35.6	7.5	6.9	1,846
TRK WELL SUPPT	1	9.8	9.8	35.6	8.0	8.6	2,443
DITCHING MACH	1	11.1	11.1	23.0	10.1	7.0	1,623
DITCHING MACH	1	8.7	8.7	27.4	7.9	10.0	2,170
EXCAVATOR CRWL	2	22.9	45.7	31.1	10.5	9.3	6,092
GRADER MOTOR	6	15.5	93.0	28.0	8.2	11.3	15,549
LOADER FULL TRAC	4	20.2	81.0	21.9	8.4	10.8	7,993
LOADER SCOOP WH	3	9.9	29.7	27.7	7.3	10.1	6,068
LOADER SCOOP WH	3	11.9	35.6	28.0	8.0	10.7	7,168
ROLLER MOTOR	1	4.0	4.0	14.6	5.7	6.5	537
ROLLER VIBRATE	3	11.8	35.3	18.3	7.6	9.8	4,067
SCRAPER-TRACTOR	8	16.0	128.0	36.6	8.8	10.3	26,499
TRC CRWLR 105 HP	3	20.1	60.3	17.8	10.6	10.3	5,804
TRC CRWLR 195HP	3	25.0	75.0	16.0	14.8	11.4	8,083
TRAC CRWLR 195HP	3	29.9	89.8	25.0	12.2	11.3	10,266
TRC WH IND RPTO	1	2.8	2.8	20.7	6.7	8.7	1,194
TRC WH LDR/BKHO	2	7.3	14.5	22.6	7.0	9.0	2,846
FLOODLIGHT TRLR	9	1.3	11.3	13.3	5.8	5.1	3,558
GEN 10KW SKID	2	0.6	1.1	3.1	2.7	5.3	86
GEN 15KW SKID	7	0.9	6.6	5.8	3.0	4.6	561
GEN 30KW SKID	7	1.4	9.6	6.7	3.0	4.6	642
GEN 60KW SKID	6	1.8	10.6	7.3	3.0	4.9	642
LUBRICATOR PWR	1	1.8	1.8	8.3	4.1	5.4	184
WELDER ARC ELEC	7	1.6	11.2	13.1	6.2	6.2	3,483
PUMP DIAPHRAGM	2	0.3	0.6	4.3	4.0	3.5	119
PUMP CENTRIFUG	3	0.8	2.3	7.1	3.0	3.6	228
PUMP CENTRIFUG	8	0.8	6.8	10.7	5.0	4.3	1,849
PUMP CENTRIFUG	1	1.7	1.7	11.8	5.7	3.5	235
SIXCON FUEL PUMP	6	1.3	7.8	6.5	8.0	4.0	1,248
SIXCON FUEL TANK	26	1.3	34.2	6.5	8.0	4.0	5,408
SIXCON WTR PUMP	3	1.2	3.5	6.5	8.0	4.0	624
SIXCON WTR TANK	10	1.3	13.5	6.5	8.0	4.0	2,080
SPRAYER DECONTM	3	1.8	5.4	10.7	7.5	4.8	1,140
PURIFIER WATER	3	0.6	1.7	6.2	3.0	3.7	204
REFRIG CONTNR	2	3.9	7.7	20.0	8.0	8.0	2,560
LAUNDRY UNIT	3	2.5	7.6	9.5	7.0	7.0	1,397
SWEEPER MAG TOW	2	0.5	1.1	5.1	9.3	3.3	313
SAW RADIAL WOOD	4	1.2	4.8	14.0	7.8	5.3	2,340
SHOP MACH TRLR	1	15.5	15.5	29.3	8.1	10.5	2,490

Mobile Const. Battalion	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
BUILD MACHINE	1	12.5	12.5	35.6	7.3	7.5	1,957
CRANE TRK 35T	3	36.6	109.9	33.3	9.2	12.8	11,688
[redacted]			[redacted]				[redacted]

Fleet Hospital	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
BUS MOTOR 36 PASS	1	8.2	8.2	27.6	8.0	10.6	2,335
TRK CARGO 4X4	1	3.1	3.1	21.7	6.4	6.3	869
TRK CARGO 4X5	1	3.1	3.1	21.7	6.4	6.3	869
TRK CARGO 4X6	1	3.1	3.1	21.7	6.4	6.3	869
TRK CARGO 4X7	1	3.1	3.1	21.7	6.4	6.3	869
TRK CARGO 4X8	1	3.1	3.1	21.7	6.4	6.3	869
AMBULANCE HEAVY	1	4.7	4.7	22.5	8.2	8.2	1,501
AMBULANCE HEAVY	1	4.7	4.7	22.5	8.2	8.2	1,501
AMBULANCE HEAVY	1	4.7	4.7	22.5	8.2	8.2	1,501
AMBULANCE HEAVY	1	4.7	4.7	22.5	8.2	8.2	1,501
AMBULANCE HEAVY	1	4.7	4.7	22.5	8.2	8.2	1,501
AMBULANCE HEAVY	1	4.7	4.7	22.5	8.2	8.2	1,501
TRK STAKE 15T 6X6	1	21.1	21.1	29.2	8.0	12.4	2,897
TRK STAKE 15T 6X6	1	21.1	21.1	29.2	8.0	12.4	2,897
TRK STAKE 15T 6X6	1	19.3	19.3	29.2	8.0	10.8	2,528
TRK DUMP 6X4 10YD	1	10.5	10.5	23.5	8.3	9.5	1,842
TRK TRACT 6X6 20T	1	10.2	10.2	25.5	8.5	10.1	2,186
TRK TRACT 6X6 20T	1	10.2	10.2	25.5	8.5	10.1	2,186
TRK TRACT 6X6 20T	1	10.2	10.2	25.5	8.5	10.1	2,186
TRK TRACT 6X6 20T	1	10.2	10.2	25.5	8.5	10.1	2,186
TRUCK MAINTENANCE TELEPHONE/UTILITY 4X4 DED	1	3.2	3.2	18.5	6.7	7.1	874
TRLR 3/4T 2 WHL	1	0.7	0.7	12.3	6.2	4.3	321
SEMITRAILER STAKE BREAKBULK/ISO CONTAINER	1	40.5	40.5	41.0	8.0	10.3	3,362
TRLR TANK 400G	1	1.4	1.4	13.5	6.7	7.0	630

Fleet Hospital	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
TRLR TANK 400G	1	1.4	1.4	13.5	6.7	7.0	630
SEMI TK 6000G	1	8.8	8.8	35.8	8.3	11.0	3,285
SEMI TK 6000G	1	8.8	8.8	35.8	8.3	11.0	3,285
SEMI TK 6000G	1	8.8	8.8	35.8	8.3	11.0	3,285
TRUCK FORKLIFT 4000 LB DED PNEUMATIC TIRE4X4	1	5.7	5.7	17.1	6.6	6.7	750
TRUCK FORKLIFT 4000 LB DED PNEUMATIC TIRE4X4	1	5.7	5.7	17.1	6.6	6.7	750
TRFK D 20K PRT	1	24.7	24.7	30.7	9.9	13.2	4,004
FLOODLIGHT SET ELECTRIC SELF-CONTAINED TRAILER-	1	1.2	1.2	12.9	6.8	5.3	463
FLOODLIGHT SET ELECTRIC SELF-CONTAINED TRAILER-	1	1.2	1.2	12.9	6.8	5.3	463
GEN 10KW SKID	1	0.6	0.6	5.2	2.7	3.1	42
GEN 10KW SKID	1	0.6	0.6	5.2	2.7	3.1	42
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
GEN 100KW SKID	1	3.8	3.8	9.0	3.3	5.4	163
LUBRICATING AND SERVICING UNIT F/DRUMS DED AIR	1	1.4	1.4	5.0	4.1	9.1	185
PUMP, FUEL, DED, 100GPM, MOUNTED IN SIXCON MODULE	1	1.4	1.4	20.0	8.0	8.0	1,280
PUMP, FUEL, DED, 100GPM, MOUNTED IN SIXCON MODULE	1	1.4	1.4	20.0	8.0	8.0	1,280
CLEANER SEPTIC TRK	1	11.4	11.4	26.8	8.0	10.3	2,194
REFRIGERATION	1	4.8	4.8	20.0	8.0	8.0	1,280

Fleet Hospital	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
REFRIGERATION	1	4.8	4.8	20.0	8.0	8.0	1,280
LAUNDRY UNIT SK	1	3.2	3.2	9.7	7.0	7.0	474
LAUNDRY UNIT SK	1	3.2	3.2	9.7	7.0	7.0	474
LAUNDRY UNIT SK	1	3.2	3.2	9.7	7.0	7.0	474
TRUCK FIRE	1	4.7	4.7	20.2	7.8	7.3	1,145
BUS AMB CONV	1	8.7	8.7	33.7	8.0	10.3	2,783
BUS AMB CONV	1	8.7	8.7	33.7	8.0	10.3	2,783
TRUCK CARGO PICKUP 4X4 6 PASSENGER 4DR 9200	1	3.1	3.1	21.5	7.0	6.3	941
TRUCK CARGO PICKUP 4X4 6 PASSENGER 4DR 9200	1	3.1	3.1	21.5	7.0	6.3	941
TRUCK CARGO PICKUP 4X4 6 PASSENGER 4DR 9200	1	3.1	3.1	21.5	7.0	6.3	941
TRUCK CARGO PICKUP 4X4 6 PASSENGER 4DR 9200	1	3.1	3.1	21.5	7.0	6.3	941
TRUCK CARGO PICKUP 4X4 6 PASSENGER 4DR 9200	1	3.1	3.1	21.5	7.0	6.3	941
TRUCK AMBULANCE FIELD COMMERCIAL 4X4 DED AUT-	1	3.2	3.2	19.0	7.2	8.5	1,157
TRUCK AMBULANCE FIELD COMMERCIAL 4X4 DED AUT-	1	3.2	3.2	19.0	7.2	8.5	1,157
TRUCK AMBULANCE FIELD COMMERCIAL 4X4 DED AUT-	1	3.2	3.2	19.0	7.2	8.5	1,157
TRUCK AMBULANCE FIELD COMMERCIAL 4X4 DED AUT-	1	3.2	3.2	19.0	7.2	8.5	1,157
TRK STAKE 15T 6X6	1	10.3	10.3	29.2	8.0	8.5	1,983
TRK STAKE 15T 6X6	1	10.3	10.3	29.2	8.0	8.5	1,983
TRK STAKE 15T 6X6	1	10.3	10.3	29.2	8.0	8.5	1,983
TRK STAKE 15T 6X6	1	10.3	10.3	29.2	8.0	8.5	1,983
TRUCK DUMP 6X6 DED AUTOMATIC TRANSMISSION 10CU	1	10.5	10.5	23.8	8.0	9.5	1,805
TRUCK TRACTOR 6X6 DED AUTOMATIC TRANSMISSION	1	10.2	10.2	24.5	8.1	10.1	1,997
TRUCK TRACTOR 6X6 DED AUTOMATIC TRANSMISSION	1	10.2	10.2	24.5	8.1	10.1	1,997
TRUCK TRACTOR 6X6 DED AUTOMATIC TRANSMISSION	1	10.2	10.2	24.5	8.1	10.1	1,997
TRUCK TRACTOR 6X6 DED AUTOMATIC TRANSMISSION	1	10.2	10.2	24.5	8.1	10.1	1,997
TRK LUBE/FUEL SER	1	9.6	9.6	24.9	8.0	8.8	1,744

Fleet Hospital	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
TRUCK MAINTENANCE TELEPHONE/UTILITY 4X4 DED	1	3.2	3.2	17.9	6.7	7.1	846
TRUCK WRECKER 6X6 DED AUTO TRANS 25 TON FRONT/	1	10.9	10.9	27.0	8.0	9.3	1,998
TRK,TANK,FUEL,SER	1	13.5	13.5	21.2	7.8	8.6	1,423
TRLR 3/4T 2 WHL	1	0.7	0.7	12.3	6.2	4.3	321
SEMITRAILER STAKE BREAKBULK/ISO CONTAINER	1	9.9	9.9	41.1	8.0	8.2	2,684
SEMITRAILER STAKE BREAKBULK/ISO CONTAINER	1	9.9	9.9	41.1	8.0	8.2	2,684
SEMITRLR LOWBOY 25	1	9.1	9.1	42.9	8.5	7.3	2,675
TRLR TK 400G	1	1.4	1.4	13.4	6.7	6.9	619
TRLR TK 400G	1	1.4	1.4	13.4	6.7	6.9	619
TRLR TK 400G	1	1.4	1.4	13.4	6.7	6.9	619
SEMI TK 5500G	1	7.8	7.8	32.3	8.0	10.0	2,580
SEMI TK 6000G	1	8.8	8.8	39.2	8.0	11.0	3,447
SEMI TK 6000G	1	8.8	8.8	39.2	8.0	11.0	3,447
SEMI TK 6000G	1	8.8	8.8	39.2	8.0	11.0	3,447
TRUCK FORKLIFT 4000 LB DED PNEUMATIC TIRE4X4	1	5.1	5.1	17.3	6.7	6.7	770
TRUCK FORKLIFT 4000 LB DED PNEUMATIC TIRE4X4	1	5.1	5.1	17.3	6.7	6.7	770
TRFK 20K PRT RTCH	1	21.5	21.5	30.7	9.9	13.3	4,029
COMPRESSOR AIR	1	3.0	3.0	16.7	8.0	6.5	867
GRADER ROAD MOTORIZED DED 125 NET HP MINIMUM	1	15.4	15.4	27.7	8.2	10.3	2,316
LOADER WHEELED	1	10.9	10.9	27.0	7.2	10.3	1,983
FLOODLIGHT SET ELECTRIC SELF-CONTAINED TRAILER-	1	1.2	1.2	12.9	6.8	5.8	515
FLOODLIGHT SET ELECTRIC SELF-CONTAINED TRAILER-	1	1.2	1.2	12.9	6.8	5.8	515
GEN 10KW SKID	1	0.6	0.6	5.5	3.0	3.6	59
GEN 10KW SKID	1	0.6	0.6	5.5	3.0	3.6	59
GEN 10KW SKID	1	0.6	0.6	5.5	3.0	3.6	59
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID	1	3.5	3.5	9.0	4.0	7.0	252

Fleet Hospital MTD 100KW AC	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
GENERATOR SET DED SKID MTD 100KW AC	1	3.5	3.5	9.0	4.0	7.0	252
WELDER ARC ELECTRIC 300 AMPS AC/DC TIG DED	1	1.6	1.6	13.1	6.2	6.7	538
PUMP WATER/TRASH RECIPROCATING 100 GPM 4 INCH	1	0.4	0.4	4.3	3.8	4.2	68
PUMP WATER/TRASH RECIPROCATING 100 GPM 4 INCH	1	0.4	0.4	4.3	3.8	4.2	68
PUMP, FUEL, DED, 100GPM, MOUNTED IN SIXCON MODULE	1	1.4	1.4	8.0	6.5	4.0	208
PUMP, FUEL, DED, 100GPM, MOUNTED IN SIXCON MODULE	1	1.4	1.4	8.0	6.5	4.0	208
CLEANER HI PRESS	1	0.4	0.4	4.9	2.7	4.0	52
CLEANER SEPTIC TK	1	5.8	5.8	26.8	8.0	11.2	2,390
CLEANER SEPTIC TK	1	5.8	5.8	26.8	8.0	11.2	2,390
8'REEFER 230/440	1	3.7	3.7	20.0	8.0	8.0	1,280
8'REEFER 230/440	1	3.7	3.7	20.0	8.0	8.0	1,280
8'REEFER 230/440	1	3.7	3.7	20.0	8.0	8.0	1,280

Fleet Hospital	MPF,E	Weight per unit (ST)	Total Weight (ST)	L (ft)	W (ft)	H (ft)	Total Vol (ft^3)
LAUNDRY UNIT 7 FOOT BY 9 FOOT SKID MOUNTED	1	2.5	2.5	9.5	7.0	7.0	466
LAUNDRY UNIT 7 FOOT BY 9 FOOT SKID MOUNTED	1	2.5	2.5	9.5	7.0	7.0	466
[illegible]			[illegible]				[illegible]

30 Days Supply Requirements for Notional MEB.

Commodity	Std. Rate (ST/day)	Weight (ST)	Volume (ft^3)	Surge Rate (ST/day)	Weight (ST)	Volume (ft^3)
Provisions	95	2,850	304,000	95	2,850	304,000
Ordnance	550	16,500	880,000	688	20,625	1,100,000
Fuel	1,063	31,890	1,253,840	1,595	47,850	1,881,349
[illegible]		[illegible]	[illegible]		[illegible]	[illegible]

APPENDIX H

Heavy Lift Aircraft and MV-22 Throughput at a 10-Hour Operating Time (shorts tons)

External Load -- Heavy Lift Aircraft

Internal Load -- MV-22

		21	20	19	18	16	15	14	13	12
		225	225	225	225	225	225	225	225	225
86	225	2307	2254	2202	2149	2044	1992	1939	1887	1834
81	225	2237	2184	2132	2079	1974	1922	1869	1817	1764
76	225	2167	2114	2062	2009	1904	1852	1799	1747	1694
72	225	2111	2058	2006	1953	1848	1796	1743	1691	1638
67	225	2041	1988	1936	1883	1778	1726	1673	1621	1568
62	225	1971	1918	1866	1813	1708	1656	1603	1551	1498
57	225	1901	1848	1796	1743	1638	1586	1533	1481	1428
52	225	1831	1778	1726	1673	1568	1516	1463	1411	1358
48	225	1775	1722	1670	1617	1512	1460	1407	1355	1302
86	250	2227	2175	2122	2070	1965	1912	1860	1807	1755
81	250	2162	2109	2057	2004	1899	1847	1794	1742	1689
76	250	2097	2044	1992	1939	1834	1782	1729	1677	1624
72	250	2044	1992	1939	1887	1782	1729	1677	1624	1572
67	250	1979	1926	1874	1821	1716	1664	1611	1559	1506
62	250	1913	1861	1808	1756	1651	1598	1546	1493	1441
57	250	1848	1796	1743	1691	1586	1533	1481	1428	1376
52	250	1783	1730	1678	1625	1520	1468	1415	1363	1310
48	250	1730	1678	1625	1573	1468	1415	1363	1310	1258
86	275	1892	1839	1787	1734	1629	1577	1524	1472	1419
81	275	1846	1794	1741	1689	1584	1531	1479	1426	1374
76	275	1800	1748	1695	1643	1538	1485	1433	1380	1328
72	275	1763	1711	1658	1606	1501	1448	1396	1343	1291
67	275	1718	1665	1613	1560	1455	1403	1350	1298	1245
62	275	1672	1619	1567	1514	1409	1357	1304	1252	1199
57	275	1626	1573	1521	1468	1363	1311	1258	1206	1153
52	275	1580	1527	1475	1422	1317	1265	1212	1160	1107
48	275	1543	1491	1438	1386	1281	1228	1176	1123	1071

		21	20	19	18	16	15	14	13	12
		250	250	250	250	250	250	250	250	250
86	225	2031	1992	1952	1913	1834	1795	1755	1716	1677
81	225	1961	1922	1882	1843	1764	1725	1685	1646	1607
76	225	1891	1852	1812	1773	1694	1655	1615	1576	1537
72	225	1835	1796	1756	1717	1638	1599	1559	1520	1481
67	225	1765	1726	1686	1647	1568	1529	1489	1450	1411
62	225	1695	1656	1616	1577	1498	1459	1419	1380	1341
57	225	1625	1586	1546	1507	1428	1389	1349	1310	1271
52	225	1555	1516	1476	1437	1358	1319	1279	1240	1201
48	225	1499	1460	1420	1381	1302	1263	1223	1184	1145
86	250	1952	1912	1873	1834	1755	1716	1676	1637	1597
81	250	1886	1847	1808	1768	1689	1650	1611	1571	1532
76	250	1821	1782	1742	1703	1624	1585	1545	1506	1467
72	250	1769	1729	1690	1651	1572	1532	1493	1454	1414
67	250	1703	1664	1624	1585	1506	1467	1428	1388	1349
62	250	1638	1598	1559	1520	1441	1402	1362	1323	1283
57	250	1572	1533	1494	1454	1376	1336	1297	1257	1218
52	250	1507	1468	1428	1389	1310	1271	1231	1192	1153
48	250	1455	1415	1376	1337	1258	1218	1179	1140	1100
86	275	1616	1577	1538	1498	1419	1380	1341	1301	1262
81	275	1570	1531	1492	1452	1374	1334	1295	1255	1216
76	275	1525	1485	1446	1406	1328	1288	1249	1210	1170
72	275	1488	1448	1409	1370	1291	1252	1212	1173	1133
67	275	1442	1403	1363	1324	1245	1206	1166	1127	1088
62	275	1396	1357	1317	1278	1199	1160	1120	1081	1042
57	275	1350	1311	1271	1232	1153	1114	1075	1035	996
52	275	1304	1265	1225	1186	1107	1068	1029	989	950
48	275	1268	1228	1189	1149	1071	1031	992	953	913

		21	20	19	18	16	15	14	13	12
		275	275	275	275	275	275	275	275	275
86	225	2031	1992	1952	1913	1834	1795	1755	1716	1677
81	225	1961	1922	1882	1843	1764	1725	1685	1646	1607
76	225	1891	1852	1812	1773	1694	1655	1615	1576	1537
72	225	1835	1796	1756	1717	1638	1599	1559	1520	1481
67	225	1765	1726	1686	1647	1568	1529	1489	1450	1411
62	225	1695	1656	1616	1577	1498	1459	1419	1380	1341
57	225	1625	1586	1546	1507	1428	1389	1349	1310	1271
52	225	1555	1516	1476	1437	1358	1319	1279	1240	1201
48	225	1499	1460	1420	1381	1302	1263	1223	1184	1145
86	250	1952	1912	1873	1834	1755	1716	1676	1637	1597
81	250	1886	1847	1808	1768	1689	1650	1611	1571	1532
76	250	1821	1782	1742	1703	1624	1585	1545	1506	1467
72	250	1769	1729	1690	1651	1572	1532	1493	1454	1414
67	250	1703	1664	1624	1585	1506	1467	1428	1388	1349
62	250	1638	1598	1559	1520	1441	1402	1362	1323	1283
57	250	1572	1533	1494	1454	1376	1336	1297	1257	1218
52	250	1507	1468	1428	1389	1310	1271	1231	1192	1153
48	250	1455	1415	1376	1337	1258	1218	1179	1140	1100
86	275	1616	1577	1538	1498	1419	1380	1341	1301	1262
81	275	1570	1531	1492	1452	1374	1334	1295	1255	1216
76	275	1525	1485	1446	1406	1328	1288	1249	1210	1170
72	275	1488	1448	1409	1370	1291	1252	1212	1173	1133
67	275	1442	1403	1363	1324	1245	1206	1166	1127	1088
62	275	1396	1357	1317	1278	1199	1160	1120	1081	1042
57	275	1350	1311	1271	1232	1153	1114	1075	1035	996
52	275	1304	1265	1225	1186	1107	1068	1029	989	950
48	275	1268	1228	1189	1149	1071	1031	992	953	913

APPENDIX I

Manning for LHA, LHA, LPD, LSD and EXWAR

LHA MANNING

DIVISION	RATING	E1-3	E4	E5	E6	E7	E8	E9	TOTAL
EXECUTIVE	JO	0	0	1	0	1	0	0	**2**
	LI	1	0	0	1	0	0	0	**2**
	MA	0	6	3	2	1	1	0	**13**
	MS	0	0	0	0	1	0	0	**1**
	NC	0	0	0	1	1	1	0	**3**
	PN	4	3	2	1	0	1	0	**11**
	ZZZZ	0	0	0	1	0	0	2	**3**
	YN	1	1	1	1	1	0	0	**5**
		6	**10**	**7**	**7**	**5**	**3**	**2**	**40**
ARGIMA	EM	0	0	1	1	0	0	0	**2**
	EN	0	0	1	0	0	0	0	**1**
	HT	0	0	0	1	1	0	0	**2**
	IC	0	0	0	1	0	0	0	**1**
	IM	0	0	0	1	0	0	0	**1**
	MM	0	0	0	2	0	0	0	**2**
	MR	0	0	0	1	0	0	0	**1**
		0	**0**	**2**	**7**	**1**	**0**	**0**	**10**
LEGAL	LN	0	0	0	1	0	0	0	**1**
CHAPLAIN	RP	0	1	0	1	0	0	0	**2**
N	QM	2	3	1	1	1	0	0	**8**
	SM	4	4	2	1	0	1	0	**12**
		6	**7**	**3**	**2**	**1**	**1**	**0**	**20**
H	HM	6	4	3	3	0	1	0	**17**
D	DT	2	1	1	0	0	0	0	**4**
OPERATIONS	YN	0	1	0	0	0	0	0	**1**
OA	AG	3	4	2	2	1	0	0	**12**
OC	AC	4	4	7	1	1	0	0	**17**

OI	OS	12	12	13	4	1	1	0	43
OZ	DM	0	0	0	1	0	0	0	1
	IS	3	3	3	2	0	1	0	12
	PH	1	3	1	1	0	0	0	6
		4	**6**	**4**	**4**	**0**	**1**	**0**	**19**
OT	CTA	0	0	1	0	0	0	0	1
	CTM	0	1	0	1	0	0	0	2
	CTO	1	2	1	1	1	0	0	6
	EW	2	1	2	1	1	0	0	7
		3	**4**	**4**	**3**	**2**	**0**	**0**	**16**
COM	RM	6	9	12	6	3	1	0	37
INFORMATION	RM	6	8	6	2	2	0	0	24
DECK	YN	0	1	0	0	0	0	0	1
1ST	BM	0	10	7	2	0	0	1	20
	ZZZZ	40	0	0	0	0	0	0	40
		40	**10**	**7**	**2**	**0**	**0**	**1**	**60**
2ND	BM	0	3	3	1	1	0	0	8
	ZZZZ	12	0	0	0	0	0	0	12
		12	**3**	**3**	**1**	**1**	**0**	**0**	**20**
AIR	YN	0	1	0	0	0	0	0	1
V-1	ABH	4	16	4	4	3	1	0	32
	ZZZZ	36	0	0	0	0	0	0	36
		40	**16**	**4**	**4**	**3**	**1**	**0**	**68**
V-3	ABH	2	10	3	1	1	1	0	18
	ZZZZ	22	0	0	0	0	0	0	22
		24	**10**	**3**	**1**	**1**	**1**	**0**	**40**
V-4	ABF	4	10	7	3	1	1	0	26
	ZZZZ	28	0	0	0	0	0	0	28
		32	**10**	**7**	**3**	**1**	**1**	**0**	**54**
IM-1	AD	0	0	0	1	0	0	0	1
	AE	0	0	0	1	0	0	0	1
	AK	0	0	1	1	0	0	0	2
	AMS	0	0	0	1	0	0	0	1
	ZZZZ	0	1	0	0	1	0	1	3

	AS	0	0	0	1	0	0	0	**1**
	AT	0	0	0	0	0	1	0	**1**
	AZ	0	1	3	1	0	0	0	**5**
	PR	0	0	0	1	0	0	0	**1**
		0	**2**	**4**	**7**	**1**	**1**	**1**	**16**
IM-2	AD	0	3	3	1	0	0	0	**7**
	AMH	0	1	0	1	0	0	0	**2**
	AMS	1	1	2	1	0	0	0	**5**
	ZZZZ	0	1	0	0	1	0	0	**2**
	AZ	0	1	0	0	0	0	0	**1**
	PR	0	1	1	0	0	0	0	**2**
		1	**8**	**6**	**3**	**1**	**0**	**0**	**19**
IM-3	AE	0	1	0	1	0	0	0	**2**
	AO	0	1	0	1	0	0	0	**2**
	ZZZZ	0	0	0	0	1	0	0	**1**
	AT	1	2	2	2	0	0	0	**7**
		1	**4**	**2**	**4**	**1**	**0**	**0**	**12**
IM-4	AK	0	0	1	0	0	0	0	**1**
	ZZZ	0	0	1	1	0	0	0	**2**
	AS	4	5	7	3	1	0	0	**20**
	AZ	0	1	0	0	0	0	0	**1**
		4	**6**	**9**	**4**	**1**	**0**	**0**	**24**
COMBAT	YN	0	1	0	0	0	0	0	**1**
CD	DS	0	9	3	2	0	1	0	**15**
CE	ET	0	11	5	3	2	0	1	**22**
	IC	3	4	5	2	0	1	0	**15**
		3	**15**	**10**	**5**	**2**	**1**	**1**	**37**
CO	ZZZZ	18	0	0	0	0	0	0	**18**
	AO	31	10	2	11	2	1	0	**57**
		49	**10**	**2**	**11**	**2**	**1**	**0**	**75**
CF	FC	0	7	3	1	1	0	0	**12**
	GM	2	2	1	1	0	0	0	**6**
		2	**9**	**4**	**2**	**1**	**0**	**0**	**18**
ENGINEERING	YN	0	1	0	0	0	0	0	**1**
A	EN	1	2	1	1	1	0	0	**6**
	ZZZZ	6	0	0	0	0	0	0	**6**
	MM	2	7	3	2	1	0	0	**15**

		9	**9**	**4**	**3**	**2**	**0**	**0**	**27**
E	EM	6	10	5	2	0	1	0	24
	ZZZZ	3	0	0	0	0	0	0	3
		9	**10**	**5**	**2**	**0**	**1**	**0**	**27**
R	DC	3	10	4	2	0	1	0	20
	ZZZZ	11	0	0	0	0	0	0	11
	HT	2	4	3	2	1	0	0	12
	MR	1	1	1	1	0	0	0	4
		17	**15**	**8**	**5**	**1**	**1**	**0**	**47**
MP	ZZZZ	26	0	0	0	0	0	0	26
	MM	8	31	8	11	2	1	1	62
		34	**31**	**8**	**11**	**2**	**1**	**1**	**88**
ASSAULT	EM	0	2	1	1	0	0	0	4
	EN	0	2	1	1	0	0	0	4
	ZZZZ	2	0	0	0	0	0	0	2
	MM	0	6	2	2	1	0	0	11
		2	**10**	**4**	**4**	**1**	**0**	**0**	**21**
SUPPLY	YN	0	1	0	0	0	0	0	1
S-1	AK	0	1	0	1	0	0	0	2
	PC	2	1	0	1	0	0	0	4
	SK	1	1	2	1	0	1	0	6
	ZZZZ	1	0	0	0	0	0	0	1
		4	**3**	**2**	**3**	**0**	**1**	**0**	**13**
S-2	ZZZZ	42	0	2	0	0	0	0	44
	MS	9	12	7	5	1	0	0	34
	MSSS	0	0	0	0	0	0	1	1
		51	**12**	**9**	**5**	**1**	**0**	**1**	**79**
S-3	SH	6	10	4	3	0	1	0	24
S-4	DK	3	2	1	1	1	0	0	8
S-5	ZZZZ	13	0	0	0	0	0	0	13
	MS	4	6	5	2	0	1	0	18
		17	**6**	**5**	**2**	**0**	**1**	**0**	**31**
S-6	AK	2	3	3	2	0	1	0	11
	ZZZZ	2	0	0	0	0	0	0	2
		4	**3**	**3**	**2**	**0**	**1**	**0**	**13**

S-8	AK	1	1	1	1	0	0	0	**4**
	AS	0	1	0	0	0	0	0	**1**
	BM	0	0	0	1	0	0	0	**1**
	DC	0	0	1	0	0	0	0	**1**
	ET	0	1	0	0	0	0	0	**1**
	ZZZZ	4	0	0	0	0	0	0	**4**
	SK	4	2	4	1	1	1	0	**13**
		9	**5**	**6**	**3**	**1**	**1**	**0**	**25**
AS	ABH	0	0	0	1	0	0	0	**1**
	AD	0	0	0	0	1	0	0	**1**
	AO	0	0	0	1	0	0	0	**1**
	BM	0	0	0	1	0	0	0	**1**
	EM	0	0	0	1	0	0	0	**1**
		0	**0**	**0**	**4**	**1**	**0**	**0**	**5**
TOTAL		**431**	**302**	**183**	**133**	**41**	**22**	**6**	**1118**
OFFICER		**DESIG**	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	
		1110	4	6	2	3	2	1	**18**
		1310	0	0	5	1	1	0	**7**
		1440	0	0	0	1	0	0	**1**
		1520	0	0	0	0	1	0	**1**
		1630	0	1	0	1	0	0	**2**
		1800	0	0	1	0	0	0	**1**
		2100	0	0	1	1	0	0	**2**
		2200	0	0	0	1	0	0	**1**
		2300	0	0	1	0	0	0	**1**
		2500	0	0	1	0	0	0	**1**
		3100	2	0	2	1	1	0	**6**
		4100	0	0	1	1	0	0	**2**
		6000	4	2	3	1	1	0	**11**
		7100	0	3	0	1	0	0	**4**
		7300	0	1	1	2	0	0	**4**
		7400	0	1	0	0	0	0	**1**
			10	**14**	**18**	**14**	**6**	**1**	**63**

LHD MANNING

DIVISION	RATING	E1-3	E4	E5	E6	E7	E8	E9	TOTAL
EXECUTIVE	JO	0	0	1	0	1	0	0	2
	LI	1	0	0	1	0	0	0	2
	MA	0	6	3	2	1	1	0	13
	MS	0	0	0	0	1	0	0	1
	NC	0	0	0	1	1	1	0	3
	PN	4	3	2	1	0	1	0	11
	YN	1	1	1	1	1	0	0	5
	ZZZZ	0	0	0	1	0	0	2	3
		6	**10**	**7**	**7**	**5**	**3**	**2**	**40**
ARGIMA	EM	0	0	1	1	0	0	0	2
	EN	0	0	1	0	0	0	0	1
	HT	0	0	0	1	1	0	0	2
	IC	0	0	0	1	0	0	0	1
	IM	0	0	0	1	0	0	0	1
	MM	0	0	0	2	0	0	0	2
	MR	0	0	0	1	0	0	0	1
		0	**0**	**2**	**7**	**1**	**0**	**0**	**10**
LEGAL	LN	0	0	0	1	0	0	0	1
CHAPLAIN	RP	0	1	0	1	0	0	0	2
N	QM	2	2	1	1	1	0	0	7
	SM	4	4	2	1	0	1	0	12
		6	**6**	**3**	**2**	**1**	**1**	**0**	**19**
H	HM	6	5	3	3	0	1	0	18
D	DT	2	1	1	0	0	0	0	4
OPERATIONS	YN	0	1	0	0	0	0	0	1
OA	AG	3	4	2	2	1	0	0	12
OC	AG	4	4	7	1	1	0	0	17
OI	OS	11	9	13	4	1	1	0	39
OZ	DM	0	0	0	1	0	0	0	1
	IS	5	4	3	2	0	1	0	15
	PH	1	3	1	1	0	0	0	6
		6	**7**	**4**	**4**	**0**	**1**	**0**	**22**

OT	CTA	0	0	1	0	0	0	0	**1**
	CTM	0	1	1	1	0	0	0	**3**
	CTO	1	2	2	1	0	0	0	**6**
	CTR	0	4	5	2	1	0	0	**12**
	EW	2	1	2	1	1	0	0	**7**
		3	**8**	**11**	**5**	**2**	**0**	**0**	**29**
CR	RM	3	9	12	6	3	1	0	34
INFORMATION	DP	0	2	0	1	0	0	0	**3**
	RM	9	6	5	1	2	0	0	**23**
		9	**8**	**5**	**2**	**2**	**0**	**0**	**26**
DECK	YN	0	1	0	0	0	0	0	**1**
1ST	BM	0	10	6	3	0	0	1	**20**
	ZZZZ	39	0	0	0	0	0	0	**39**
		39	**10**	**6**	**3**	**0**	**0**	**1**	**59**
2ND	BM	0	4	3	1	1	0	0	**9**
	ZZZZ	16	0	0	0	0	0	0	**16**
		16	**4**	**3**	**1**	**1**	**0**	**0**	**25**
V-1	ABH	4	16	4	4	3	1	0	**32**
	ZZZZ	39	0	0	0	0	0	0	**39**
	YN	0	1	0	0	0	0	0	**1**
		43	**17**	**4**	**4**	**3**	**1**	**0**	**72**
V-3	ABH	2	11	4	3	1	1	0	**22**
	ZZZZ	22	0	0	0	0	0	0	**22**
		24	**11**	**4**	**3**	**1**	**1**	**0**	**44**
V-4	ABF	4	10	4	3	1	1	0	**23**
	ZZZZ	26	0	0	0	0	0	0	**26**
		30	**10**	**4**	**3**	**1**	**1**	**0**	**49**
IM-1	AD	0	0	0	1	0	0	0	**1**
	AE	0	0	0	1	0	0	0	**1**
	AK	0	0	1	1	0	0	0	**2**
	AMS	0	0	0	1	0	0	0	**1**
	ZZZZ	0	1	0	0	1	0	1	**3**
	AS	0	0	0	1	0	0	0	**1**
	AT	0	0	0	0	0	1	0	**1**
	AZ	0	0	3	1	0	0	0	**4**
	PR	0	0	0	1	0	0	0	**1**
		0	**1**	**4**	**7**	**1**	**1**	**1**	**15**

IM-2	AD	0	3	3	1	0	0	0	**7**
	AMH	0	1	0	1	0	0	0	**2**
	AMS	1	0	3	1	0	0	0	**5**
	ZZZZ	0	1	0	0	1	0	0	**2**
	AZ	0	1	0	0	0	0	0	**1**
	PR	0	1	1	0	0	0	0	**2**
		1	**7**	**7**	**3**	**1**	**0**	**0**	**19**
IM-3	AE	0	1	0	1	0	0	0	**2**
	AO	0	1	0	1	0	0	0	**2**
	ZZZZ	0	0	0	0	1	0	0	**1**
	AT	1	2	2	2	0	0	0	**7**
		1	**4**	**2**	**4**	**1**	**0**	**0**	**12**
IM-4	AK	0	0	1	0	0	0	0	**1**
	ZZZ	0	0	1	1	0	0	0	**2**
	AS	4	5	7	3	1	0	0	**20**
	AZ	0	1	0	0	0	0	0	**1**
		4	**6**	**9**	**4**	**1**	**0**	**0**	**24**
COMBAT	YN	0	1	0	0	0	0	0	**1**
CD	DS	0	10	6	2	1	1	0	**20**
CE	ET	0	10	7	3	2	0	1	**23**
	IC	5	4	6	2	0	1	0	**18**
		5	**14**	**13**	**5**	**2**	**1**	**1**	**41**
CO	ZZZZ	3	0	0	0	0	0	0	**3**
	AO	30	8	3	9	2	1	0	**53**
		33	**8**	**3**	**9**	**2**	**1**	**0**	**56**
CG	FC	0	4	1	1	1	0	0	**7**
	GM	0	0	0	0	1	0	0	**1**
	GMG	1	1	1	1	0	0	0	**4**
		1	**5**	**2**	**2**	**2**	**0**	**0**	**12**
CM	FC	6	8	4	2	0	1	0	**21**
ENGINEERING	YN	0	1	0	0	0	0	0	**1**
A	EN	0	6	1	1	1	0	0	**9**
	ZZZZ	4	0	0	0	0	0	0	**4**
	MM	0	7	3	2	1	0	0	**13**
		4	**13**	**4**	**3**	**2**	**0**	**0**	**26**

E	EM	8	14	7	3	0	1	0	**33**
	ZZZZ	4	0	0	0	0	0	0	**4**
		12	**14**	**7**	**3**	**0**	**1**	**0**	**37**
R	DC	1	12	5	1	1	1	0	**21**
	ZZZZ	12	0	0	0	0	0	0	**12**
	HT	4	4	3	2	1	0	0	**14**
	MR	1	1	1	1	0	0	0	**4**
		18	**17**	**9**	**4**	**2**	**1**	**0**	**51**
MP	ZZZZ	34	0	0	0	0	0	0	**34**
	MM	10	27	10	8	2	1	1	**59**
		44	**27**	**10**	**8**	**2**	**1**	**1**	**93**
ASSAULT	EM	0	2	1	1	0	0	0	**4**
	EN	0	3	1	1	0	0	0	**5**
	MM	0	8	2	2	1	0	0	**13**
		0	**13**	**4**	**4**	**1**	**0**	**0**	**22**
S-1	AK	0	1	0	1	0	0	0	**2**
	PC	2	1	0	1	0	0	0	**4**
	SK	1	2	2	1	0	1	0	**7**
	ZZZZ	1	0	0	0	0	0	0	**1**
	YN	0	1	0	0	0	0	0	**1**
		4	**5**	**2**	**3**	**0**	**1**	**0**	**15**
S-2	ZZZZ	43	0	2	0	0	0	0	**45**
	MS	9	12	7	5	1	0	0	**34**
	MSSS	0	0	0	0	0	0	1	**1**
		52	**12**	**9**	**5**	**1**	**0**	**1**	**80**
S-3	SH	5	11	5	3	0	1	0	**25**
S-4	DK	3	2	1	1	1	0	0	**8**
S-5	ZZZZ	13	0	0	0	0	0	0	**13**
	MS	4	6	5	2	0	1	0	**18**
		17	**6**	**5**	**2**	**0**	**1**	**0**	**31**
S-6	AK	2	2	4	1	1	1	0	**11**
	ZZZZ	2	0	0	0	0	0	0	**2**
		4	**2**	**4**	**1**	**1**	**1**	**0**	**13**
S-8	AK	1	1	2	1	0	0	0	**5**
	AS	0	1	0	0	0	0	0	**1**
	BM	0	0	0	1	0	0	0	**1**
	DC	0	0	1	0	0	0	0	**1**

	ET	0	1	0	0	0	0	0	1
	ZZZZ	4	0	0	0	0	0	0	4
	SK	4	2	5	1	1	1	0	14
		9	5	8	3	1	1	0	27
AS	ABH	0	0	0	1	0	0	0	1
	AD	0	0	0	0	1	0	0	1
	AO	0	0	0	1	0	0	0	1
	BM	0	0	0	1	0	0	0	1
	EM	0	0	0	1	0	0	0	1
		0	0	0	4	1	0	0	5
TOTAL		434	318	209	141	46	24	7	1179
OFFICER		DESIG	O1	O2	O3	O4	O5	O6	
		1110	4	6	3	3	2	1	19
		1310	0	0	3	3	1	0	7
		1440	0	0	0	1	0	0	1
		1610	0	0	1	0	0	0	1
		1630	0	1	0	1	0	0	2
		1800	0	0	1	0	0	0	1
		2100	0	0	1	1	0	0	2
		2200	0	0	1	1	0	0	2
		2300	0	0	1	0	0	0	1
		2500	0	0	1	0	0	0	1
		3100	3	0	3	1	1	0	8
		4100	0	0	1	1	0	0	2
		6000	4	1	3	1	2	0	11
		7100	0	3	0	1	0	0	4
		7300	0	1	2	1	0	0	4
		7400	0	1	0	0	0	0	1
			11	13	21	15	6	1	67

LPD MANNING

DIVISION	RATING	E1-3	E4	E5	E6	E7	E8	E9	TOTAL
EXECUTIVE	LI	0	0	1	0	0	0	0	**1**
	MA	0	1	0	1	0	0	0	**2**
	NC	0	0	0	1	0	0	0	**1**
	PN	1	1	1	0	1	0	0	**4**
	ZZZZ	0	0	0	1	0	0	2	**3**
	RP	0	0	1	0	0	0	0	**1**
	YN	0	0	1	1	0	0	0	**2**
		1	**2**	**4**	**4**	**1**	**0**	**2**	**14**
N	QM	1	2	1	1	1	0	0	**6**
	SM	4	4	2	1	1	0	0	**12**
		5	**6**	**3**	**2**	**2**	**0**	**0**	**18**
H	HM	2	2	1	1	1	0	0	**7**
D	DT	1	1	1	0	0	0	0	**3**
OPERATIONS	YN	0	1	0	0	0	0	0	**1**
OC	RM	1	6	5	3	0	1	0	**16**
OE	ET	0	5	3	1	1	0	0	**10**
OI	OS	6	7	5	2	1	0	0	**21**
OEM	FC	0	3	1	1	0	0	0	**5**
OT	EW	0	2	1	1	0	0	0	**4**
	IS	0	0	0	1	0	0	0	**1**
		0	**2**	**1**	**2**	**0**	**0**	**0**	**5**
DECK	YN	1	0	0	0	0	0	0	**1**

1ST	BM	0	8	5	1	0	1	0	**15**
	ZZZZ	31	0	0	0	0	0	0	**31**
		31	**8**	**5**	**1**	**0**	**1**	**0**	**46**
2ND	BM	0	4	3	1	1	0	0	**9**
	ZZZZ	14	0	0	0	0	0	0	**14**
		14	**4**	**3**	**1**	**1**	**0**	**0**	**23**
3RD	GM	1	2	1	1	1	0	0	**6**
V	ABF	1	2	1	0	1	0	0	**5**
	ABH	0	3	1	1	0	0	0	**5**
	ZZZZ	5	0	0	0	0	0	0	**5**
	AS	0	2	1	0	0	0	0	**3**
		6	**7**	**3**	**1**	**1**	**0**	**0**	**18**
ENGINEERING	YN	1	0	0	0	0	0	0	**1**
A	EN	1	4	1	1	0	0	0	**7**
	ZZZZ	1	0	0	0	0	0	0	**1**
	MM	0	4	1	1	1	0	0	**7**
		2	**8**	**2**	**2**	**1**	**0**	**0**	**15**
B	ZZZZ	5	0	0	0	0	0	0	**5**
	MM	6	14	3	4	1	1	0	**29**
		11	**14**	**3**	**4**	**1**	**1**	**0**	**34**
E	EM	0	8	2	1	1	0	0	**12**
	ZZZZ	1	0	0	0	0	0	0	**1**
	IC	0	2	1	1	0	0	0	**4**
		1	**10**	**3**	**2**	**1**	**0**	**0**	**17**
M	ZZZZ	6	0	0	0	0	0	0	**6**
	MM	0	21	3	5	1	0	1	**31**
		6	**21**	**3**	**5**	**1**	**0**	**1**	**37**
R	DC	1	3	2	2	1	0	0	**9**
	ZZZZ	3	0	0	0	0	0	0	**3**
	HT	2	1	1	1	0	0	0	**5**
	MR	1	0	1	0	0	0	0	**2**
		7	**4**	**4**	**3**	**1**	**0**	**0**	**19**
S-1	ZZZZ	4	0	1	0	0	0	0	**5**
	BM	0	0	1	0	0	0	0	**1**

	PC	0	1	0	1	0	0	0	**2**
	SK	3	1	3	1	1	0	0	**9**
		7	**2**	**5**	**2**	**1**	**0**	**0**	**17**
S-2	ZZZZ	21	0	0	0	0	0	0	**21**
	MS	3	4	3	2	0	1	0	**13**
		24	**4**	**3**	**2**	**0**	**1**	**0**	**34**
S-3	SH	1	4	2	1	1	0	0	**9**
S-4	DK	1	1	0	1	0	0	0	**3**
S-5	ZZZZ	6	0	0	0	0	0	0	**6**
	MS	3	2	1	1	0	0	0	**7**
		9	**2**	**1**	**1**	**0**	**0**	**0**	**13**
TOTAL		**139**	**126**	**62**	**43**	**16**	**4**	**3**	**393**
OFFICER		**DESIG**	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	
		1110	4	6	3	3	2	1	**19**
		1310	0	0	3	3	1	0	**7**
		2100	0	0	1	1	0	0	**2**
		2200	0	0	1	1	0	0	**2**
		3100	3	0	3	1	1	0	**8**
		4100	0	0	1	1	0	0	**2**
		6000	4	1	3	1	2	0	**11**
		7100	0	3	0	1	0	0	**4**
			11	**10**	**15**	**12**	**6**	**1**	**55**

LSD MANNING

DIVISION	RATING	E1-3	E4	E5	E6	E7	E8	E9	TOTAL
EXECUTIVE	JO	0	1	0	0	0	0	0	**1**
	MA	0	1	0	0	1	0	0	**2**
	NC	0	0	0	1	0	0	0	**1**
	PN	1	1	1	0	1	0	0	**4**
	ZZZZ	0	0	0	0	0	1	1	**2**
	YN	0	1	1	1	0	0	0	**3**
		1	**4**	**2**	**2**	**2**	**1**	**1**	**13**
N	QM	1	2	1	1	1	0	0	**6**
	SM	1	3	2	1	1	0	0	**8**
		2	**5**	**3**	**2**	**2**	**0**	**0**	**14**
H	HM	2	2	1	1	0	1	0	**7**
D	DT	1	1	1	0	0	0	0	**3**
OC	RM	2	4	4	1	1	0	0	**12**
OE	ET	0	5	2	1	1	0	0	**9**
OI	EW	0	2	1	1	0	0	0	**4**
	OS	6	3	5	1	1	0	0	**16**
		6	**5**	**6**	**2**	**1**	**0**	**0**	**20**
OEM	FC	0	3	1	1	0	0	0	**5**
DECK	YN	1	0	0	0	0	0	0	**1**
1ST	BM	0	6	4	1	0	1	0	**12**
	ZZZZ	21	0	0	0	0	0	0	**21**
		21	**6**	**4**	**1**	**0**	**1**	**0**	**33**
2ND	BM	0	4	3	1	1	0	0	**9**
	ZZZZ	22	0	0	0	0	0	0	**22**
		22	**4**	**3**	**1**	**1**	**0**	**0**	**31**
3RD	GM	2	2	2	1	1	0	0	**8**

	ZZZZ	2	0	0	0	0	0	0	**2**
		4	**2**	**2**	**1**	**1**	**0**	**0**	**10**
ENGINEERING	YN	1	0	0	0	0	0	0	**1**
A	EN	3	5	2	2	1	0	0	**13**
	ZZZZ	2	0	0	0	0	0	0	**2**
	MM	1	0	1	0	0	0	0	**2**
		6	**5**	**3**	**2**	**1**	**0**	**0**	**17**
E	EM	0	8	2	1	1	0	0	**12**
	ZZZZ	1	0	0	0	0	0	0	**1**
	IC	0	5	1	1	0	0	0	**7**
		1	**13**	**3**	**2**	**1**	**0**	**0**	**20**
M	EN	0	20	4	6	1	0	1	**32**
	ZZZZ	17	0	0	0	0	0	0	**17**
		17	**20**	**4**	**6**	**1**	**0**	**1**	**49**
R	DC	1	9	3	2	0	1	0	**16**
	ZZZZ	4	0	0	0	0	0	0	**4**
	HT	1	2	2	1	1	0	0	**7**
	MR	0	0	1	0	0	0	0	**1**
		6	**11**	**6**	**3**	**1**	**1**	**0**	**28**
S-1	BM	0	0	1	0	0	0	0	**1**
	PC	0	0	1	1	0	0	0	**2**
	SK	3	2	3	1	1	0	0	**10**
	ZZZZ	1	0	1	0	0	0	0	**2**
		4	**2**	**6**	**2**	**1**	**0**	**0**	**15**
S-2	ZZZZ	14	0	0	0	0	0	0	**14**
	MS	4	4	3	4	0	1	0	**16**
		18	**4**	**3**	**4**	**0**	**1**	**0**	**30**
S-3	SH	1	3	1	1	1	0	0	**7**
S-4	DK	1	0	0	1	0	0	0	**2**
S-5	ZZZZ	6	0	0	0	0	0	0	**6**
	MS	3	2	1	1	0	0	0	**7**
		9	**2**	**1**	**1**	**0**	**0**	**0**	**13**
LOG SUPPORT	EN	0	0	1	0	0	0	0	**1**
	ET	0	0	1	0	0	0	0	**1**
	SK	0	0	0	1	0	0	0	**1**
		0	**0**	**2**	**1**	**0**	**0**	**0**	**3**

TOTAL		**126**	**101**	**58**	**36**	**15**	**5**	**2**	**343**
OFFICER		**DESIG**	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	
		1110	6	5	3	1	1	0	**16**
		2100	0	0	1	0	0	0	**1**
		2200	0	0	0	1	0	0	**1**
		3100	1	0	1	0	0	0	**2**
		6000	0	1	0	0	0	0	**1**
		7100	0	2	0	0	0	0	**2**
			7	**8**	**5**	**2**	**1**	**0**	**23**

EXWAR MANNING

RATING	E1-3	E4	E5	E6	E7	E8	E9	TOTAL
ABF	0	7	3	2	0	0	0	12
ABH	0	15	5	4	0	0	0	24
AC	0	4	3	1	0	0	0	8
AK	0	13	5	3	0	0	0	21
BM	0	35	10	5	0	0	0	50
DC	0	7	3	2	0	0	0	12
DK	0	0	1	1	0	0	0	2
DT	0	7	4	1	0	0	0	12
EM	0	10	9	3	0	0	0	22
EN	0	1	1	0	0	0	0	2
ET	0	11	3	4	0	0	0	18
EW	0	0	2	2	0	0	0	4
FC	0	20	8	6	0	0	0	34
GMG	0	10	5	3	0	0	0	18
GS	0	8	4	4	0	0	0	16
HM	0	10	7	3	0	0	0	20
HT	0	4	2	1	0	0	0	7
IC	0	4	2	1	0	0	0	7
LN	0	1	1	0	0	0	0	2
MA	0	2	2	1	0	0	0	5
MM	0	13	9	2	0	0	0	24
MR	0	3	2	1	0	0	0	6
MS	0	25	15	12	0	0	0	52
OS	0	15	5	4	0	0	0	24
PN	0	2	1	0	0	0	0	3
QM	0	2	1	1	0	0	0	4
RM	0	10	6	4	0	0	0	20
SH	0	16	9	5	0	0	0	30
SK	0	16	10	4	0	0	0	30
STG	0	4	4	3	0	0	0	11
TM	0	0	1	1	0	0	0	2
YN	0	6	1	1	0	0	0	8
ZZZZ	0	55	35	16	30	10	1	147
	0	**336**	**179**	**101**	**30**	**10**	**1**	**657**
OFFICER	**DESIG**	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	
	1110	5	5	6	2	1	1	20
	1310	0	0	2	1	1	0	4
	2200	0	0	2	1	0	0	3
	2300	0	0	2	1	0	0	3
	2500	0	0	1	0	0	0	1
	3100	0	1	3	1	0	0	5
	4100	0	0	0	1	0	0	1
	6000	0	2	1	3	1	0	7
TOTAL		**5**	**8**	**17**	**10**	**3**	**1**	**44**

APPENDIX J

Hydrostatic Data

Hull Data (with appendages)

Baseline Draft: 40.000
Trim: zero
Heel: stbd 0.33 deg.

DIMENSIONS
Length Overall: 990.000 ft LWL: 989.980 ft Beam: 300.000 ft BWL: 405.451 ft
Volume: 2867472.000 ft^3 Displacement: 81911.410 LT

COEFFICIENTS
Prismatic: 0.572 Block: 0.240 Midship: 0.419 Waterplane: 0.245

RATIOS
Length/Beam: 3.300 Displacement/length: 84.424 Beam/Depth: 7.449
LT/inch Immersion: 233.986

AREAS
Waterplane: 98293.700 ft^2 Wetted Surface: 187639.900 ft^2
Under Water Lateral Plane: 48694.860 ft^2 Above Water Lateral Plane: 75811.920 ft^2

CENTROIDS (Feet)
Buoyancy: LCB = 573.064 aft TCB =0.801 stbd VCB = 23.525
Flotation: LCF = 590.617 aft
Under Water LP: 485.470 aft of Origin, 17.458 below waterline.
Above Water LP: 541.528 aft of Origin, 27.965 above waterline.

Note: Coefficients calculated based on waterline length at given draft

Hydrostatic Properties

No Trim, heel: stbd 0.33 deg.

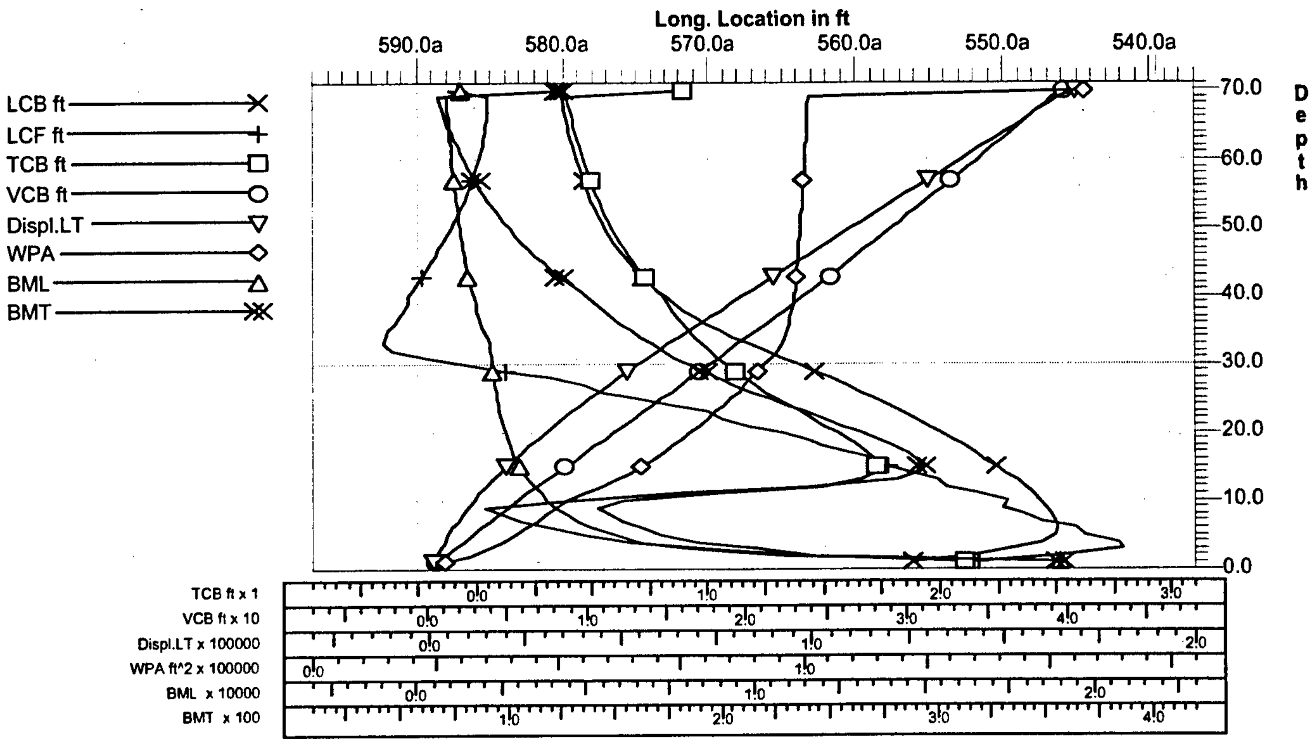
Depth (ft)	Displ (LT)	LCB (ft)	TCB (ft)	VCB (ft)	WPA (ft^2)	LCF (ft)	BML (ft)	BMT (ft)
1.000	675.404	556.339a	2.107s	0.517	26339	551.772a	18,958.460	357.193
2.000	1510.790	552.467a	1.462s	1.077	31674	546.611a	10,983.310	243.097
3.000	2473.067	549.536a	1.219s	1.641	35205	542.009a	7,968.950	191.185
4.000	3524.637	547.431a	0.951s	2.200	38193	542.180a	6,627.826	157.443
5.000	4659.030	546.542a	0.800s	2.763	41026	544.623a	5,868.388	135.051
6.000	5866.387	546.398a	0.712s	3.328	43159	545.235a	5,192.786	118.355
7.000	7135.230	546.523a	0.629s	3.893	45407	547.528a	4,770.116	106.121
8.000	8462.039	546.852a	0.567s	4.460	47318	548.709a	4,397.623	96.400
9.000	9839.839	547.195a	0.524s	5.027	49199	550.106a	4,116.587	88.796

10.000	11280.060	547.643a	0.629s	5.600	51603	549.841a	3,826.042	129.504
11.000	12801.570	548.104a	1.066s	6.186	54904	551.934a	3,661.428	180.560
12.000	14422.420	548.639a	1.492s	6.787	58510	553.894a	3,484.522	241.266
13.000	16141.620	549.249a	1.657s	7.398	61680	554.580a	3,304.416	280.534
14.000	17943.920	549.904a	1.709s	8.013	64280	556.110a	3,168.683	289.274
15.000	19816.770	550.574a	1.725s	8.628	66820	557.999a	3,059.623	292.876
16.000	21758.190	551.295a	1.718s	9.242	68817	558.269a	2,916.230	290.165
17.000	23761.620	552.027a	1.685s	9.856	71118	560.412a	2,834.931	286.430
18.000	25824.890	552.780a	1.645s	10.467	73243	562.499a	2,762.139	279.021
19.000	27945.160	553.570a	1.603s	11.078	75020	563.395a	2,665.890	272.402
20.000	30119.540	554.396a	1.554s	11.687	76875	565.203a	2,599.717	263.997
21.000	32344.620	555.229a	1.500s	12.294	78774	567.341a	2,550.530	255.857
22.000	34619.300	556.082a	1.449s	12.899	80508	569.263a	2,501.744	247.108
23.000	36944.070	556.981a	1.401s	13.504	81933	570.168a	2,435.513	238.651
24.000	39313.930	557.892a	1.349s	14.107	83593	572.518a	2,403.813	230.002
25.000	41728.220	558.831a	1.297s	14.709	85267	575.141a	2,380.445	221.566
26.000	44185.510	559.795a	1.249s	15.309	86810	577.456a	2,354.076	213.372
27.000	46684.550	560.785a	1.205s	15.909	88002	578.692a	2,304.085	205.425
28.000	49223.690	561.803a	1.160s	16.507	89375	580.952a	2,274.997	197.980
29.000	51800.930	562.847a	1.117s	17.104	90849	583.986a	2,258.368	190.926
30.000	54416.700	563.934a	1.077s	17.701	92277	586.875a	2,242.123	184.253
31.000	57071.090	565.058a	1.042s	18.296	93556	589.321a	2,215.209	178.029
32.000	59763.330	566.218a	1.008s	18.891	94794	591.702a	2,186.860	172.299
33.000	62483.760	567.349a	0.975s	19.484	95586	592.319a	2,128.952	166.959
34.000	65223.140	568.397a	0.945s	20.073	96180	592.255a	2,061.677	161.934
35.000	67977.910	569.358a	0.918s	20.658	96665	591.954a	1,991.511	157.222
36.000	70745.020	570.236a	0.892s	21.239	97057	591.638a	1,919.031	152.775
37.000	73522.860	571.036a	0.868s	21.815	97425	591.219a	1,852.064	148.659
38.000	76310.670	571.769a	0.845s	22.389	97756	590.965a	1,786.329	144.824
39.000	79107.670	572.444a	0.824s	22.958	98090	590.664a	1,725.963	141.205
40.000	81913.330	573.064a	0.801s	23.525	98294	590.617a	1,665.463	137.116
41.000	84723.780	573.643a	0.775s	24.088	98476	590.346a	1,614.332	132.952
42.000	87538.290	574.176a	0.748s	24.648	98584	590.051a	1,567.373	128.420
43.000	90356.040	574.666a	0.723s	25.205	98694	589.741a	1,523.542	124.169
44.000	93176.800	575.118a	0.699s	25.759	98802	589.445a	1,482.141	120.160
45.000	96000.770	575.535a	0.677s	26.310	98912	589.140a	1,443.244	116.425
46.000	98827.840	575.920a	0.657s	26.859	99019	588.849a	1,406.327	112.892
47.000	101658.000	576.275a	0.637s	27.406	99121	588.581a	1,371.087	109.557
48.000	104490.900	576.605a	0.619s	27.951	99226	588.304a	1,337.814	106.410
49.000	107326.900	576.911a	0.602s	28.494	99333	588.020a	1,306.351	103.441
50.000	110165.900	577.194a	0.585s	29.035	99438	587.756a	1,276.195	100.635
51.000	113007.900	577.456a	0.570s	29.575	99541	587.510a	1,247.284	97.979
52.000	115852.900	577.700a	0.555s	30.114	99643	587.275a	1,219.681	95.461
53.000	118700.800	577.927a	0.541s	30.651	99746	587.037a	1,193.486	93.059
54.000	121551.500	578.138a	0.528s	31.187	99845	586.835a	1,168.138	90.775
55.000	124405.100	578.335a	0.515s	31.721	99940	586.653a	1,143.704	88.615
56.000	127261.400	578.519a	0.503s	32.255	100037	586.464a	1,120.466	86.544
57.000	130120.500	578.692a	0.492s	32.788	100136	586.276a	1,098.231	84.575
58.000	132982.400	578.853a	0.481s	33.320	100235	586.099a	1,076.819	82.703
59.000	135847.000	579.004a	0.471s	33.851	100328	585.968a	1,055.879	80.939
60.000	138714.500	579.147a	0.461s	34.381	100423	585.844a	1,035.811	79.248

61.000	141584.600	579.281a	0.451s	34.910	100520	585.715a	1,016.636	77.634
62.000	144457.300	579.408a	0.442s	35.439	100612	585.613a	997.935	76.085
63.000	147332.600	579.528a	0.434s	35.967	100698	585.531a	979.701	74.614
64.000	150210.500	579.643a	0.426s	36.495	100786	585.445a	962.237	73.193
65.000	153090.900	579.751a	0.418s	37.021	100877	585.361a	945.449	71.843
66.000	155973.800	579.854a	0.410s	37.548	100965	585.301a	929.069	70.549
67.000	158859.000	579.953a	0.403s	38.074	101044	585.293a	912.872	69.315
68.000	161746.500	580.048a	0.396s	38.599	101122	585.286a	897.248	68.116
69.000	164636.300	580.140a	0.389s	39.124	101202	585.266a	882.296	66.948
70.000	168401.200	580.280a	0.896s	39.807	157474	587.182a	1,259.864	124.342

Water Specific Gravity = 1.025.

Hydrostatic Properties at Trim = 0.00, Heel = 0.33s



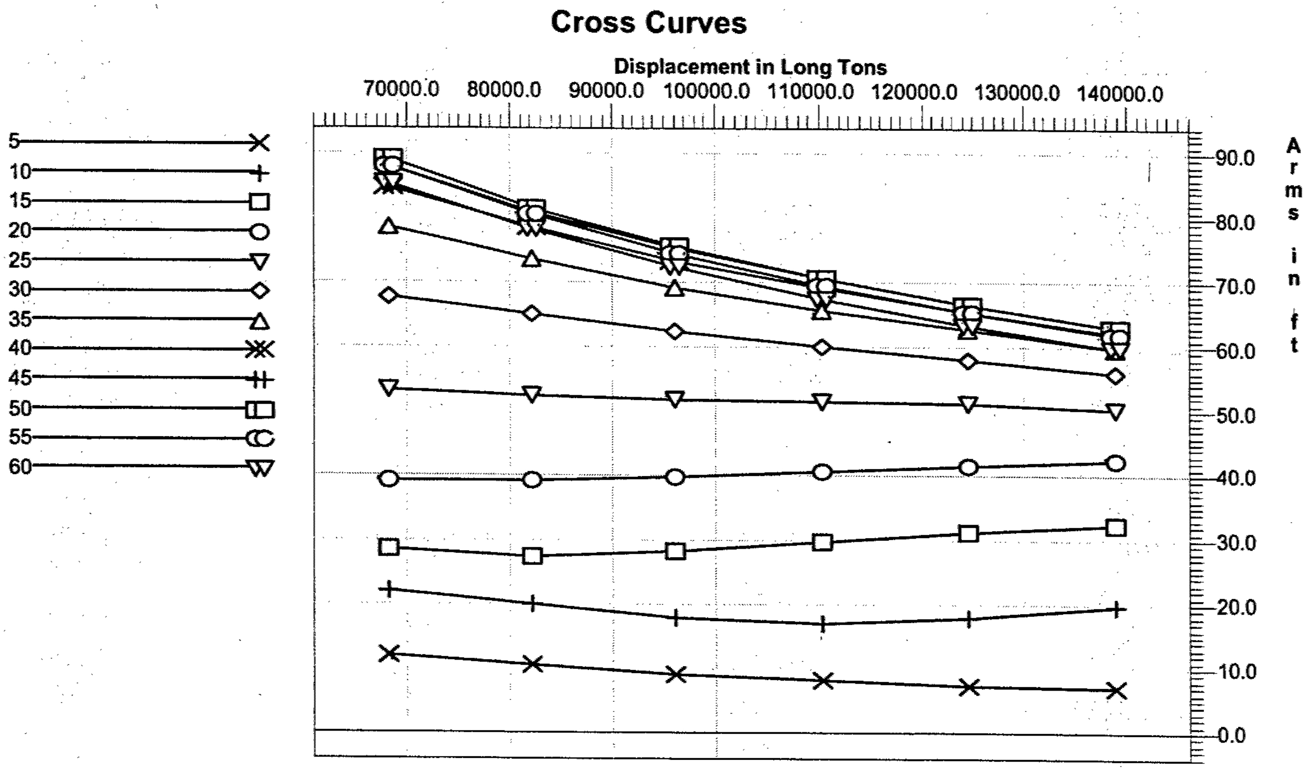
Cross Curves of Stability

Righting Arms(heel) for VCG = 35.00
Trim zero at heel = 0 (RA Trim = 0)

Displ (LT)	5.000s	10.000s	15.000s	20.000s	25.000s	30.000s	35.000s
67974.050	12.293s	22.204s	28.699s	39.222s	53.358s	67.936s	78.571s
81910.670	10.619s	20.149s	27.617s	39.202s	52.439s	65.103s	73.624s
95999.020	9.318s	18.121s	28.425s	39.827s	52.048s	62.480s	69.386s
110163.800	8.301s	17.298s	29.977s	40.716s	51.723s	60.118s	65.762s
124402.700	7.491s	18.184s	31.416s	41.684s	51.195s	58.009s	62.662s
138711.600	7.261s	19.738s	32.588s	42.641s	50.542s	56.106s	59.883s

Displ (LT)	40.000s	45.000s	50.000s	55.000s	60.000s	Arm	Angle
67974.050	84.925s	88.177s	89.183s	88.173s	85.580s		
81910.670	78.653s	81.093s	81.666s	80.703s	78.337s		
95999.020	73.481s	75.386s	75.659s	74.607s	72.447s	74.953s	53.875s
110163.800	69.177s	70.723s	70.792s	69.662s	67.546s	70.898s	46.740s
124402.700	65.479s	66.727s	66.640s	65.483s	63.447s	65.357s	39.675s
138711.600	62.177s	63.161s	63.000s	61.860s	59.910s	57.450s	31.552s

Water Specific Gravity = 1.025.



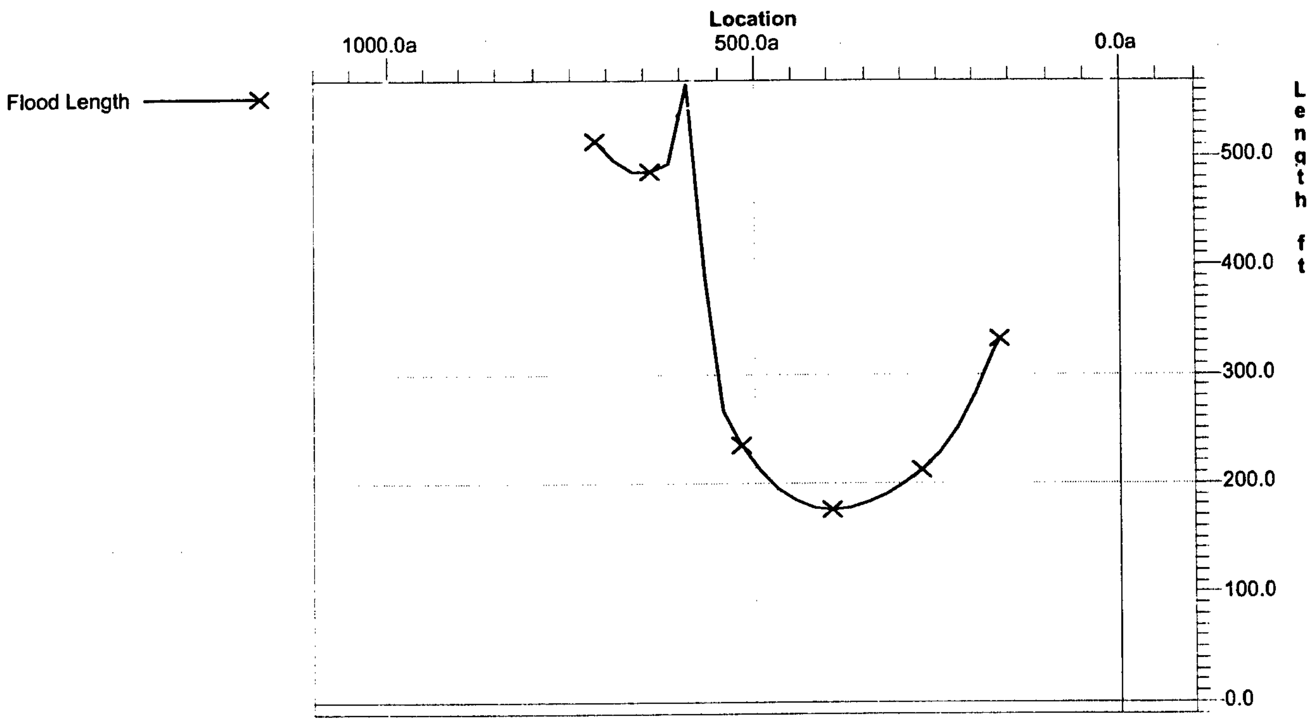
Floodable Length Calculation

Displacement: 81910.67LT   Water Specific Gravity: 1.025   Draft: 40.00 ft
L: 573.063a   T: 0.000   V: 0.000 ft
Permeability varied
fl 40 /Perm:0,0.98,200,0.95,340,0.85,500,0.95,700,0.95

Center (ft)	Length (ft)	Trim (deg)
166.164a	332.33	2.334f
173.250a	320.64	2.344f
198.000a	282.99	2.326f
222.750a	252.04	2.316f
247.500a	228.41	2.288f
272.250a	213.24	2.250f

297.000a	200.02	2.213f
321.750a	190.45	2.163f
346.500a	183.75	2.109f
371.250a	178.37	2.045f
396.000a	176.97	1.976f
420.750a	178.27	1.892f
445.500a	184.54	1.792f
470.250a	196.16	1.660f
495.000a	213.22	1.492f
519.750a	235.95	1.271f
544.500a	266.65	0.959f
569.250a	391.28	0.494f
594.000a	566.59	0.159a
618.750a	493.56	0.684a
643.500a	485.84	1.116a
668.250a	486.46	1.465a
693.000a	496.54	1.741a
717.750a	514.90	1.962a

Floodable Lengths



Residual Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (ft)	Residual Arm (ft)	Area (ft-Deg)	Flood Pt Height (ft)	Notes
0.00	0.00	40.00	-0.73	0.000	30.00 (1)	

0.33s	0.00	40.00	0.00	-0.122	29.74 (2)	Equil
10.00s	0.02f	39.21	19.41	93.719	21.97 (2)	
15.00s	0.01f	37.02	26.88	210.192	19.00 (2)	
20.00s	0.03f	33.14	38.47	371.851	17.36 (2)	
30.00s	0.20f	23.96	64.37	882.993	14.95 (2)	
40.00s	0.55f	15.89	77.89	1604.617	11.01 (2)	
50.00s	0.99f	8.39	80.93	2407.474	6.10 (2)	
60.00s	1.35f	-0.13	77.60	3205.439	1.56 (2)	
64.63s	1.44f	-4.90	74.38	3557.916	0.00 (2)	FldPt
70.00s	1.52f	-10.62	69.63	3944.852	-1.64 (2)	
80.00s	1.62f	-21.37	58.31	4587.203	-4.26 (2)	
90.00s	1.83f	-31.06	44.04	5101.432	-6.56 (2)	

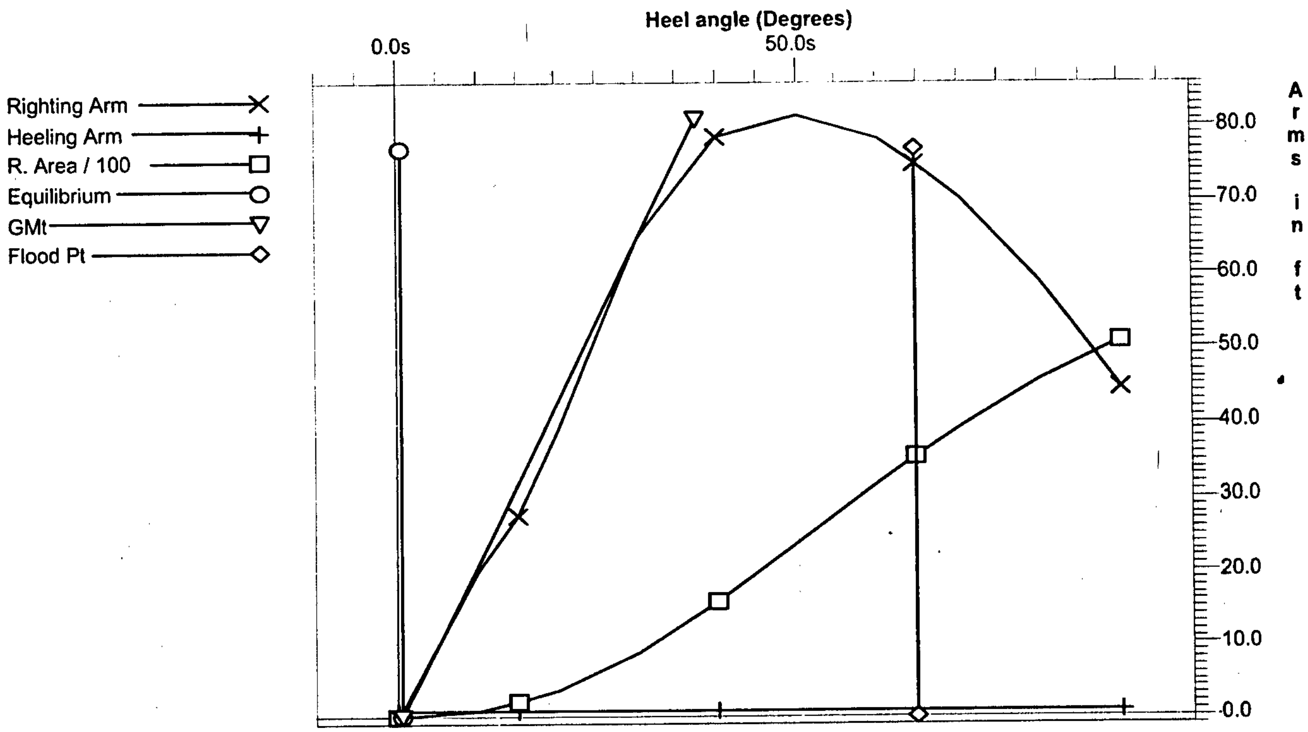
Note:
Residual Righting Arms shown above are in excess of the wind heeling arms derived from this moment (in ft-LT):
Stbd heeling moment = 60186.01

Unprotected Flood Points

Name	L,T,V (ft)	Height (ft)
(1) Engine Port Intake	230.000a, 45.000p, 70.000	30.000
(2) Engine Stbd Intake	230.000a, 45.000s, 70.000	29.738

IMO RESOLUTION A.167

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.055 ft-D		<large>	Yes
(2) Area at 30.00 deg	>0.015 ft-D		<large>	Yes
(3) Area from 0.00 deg to 40.00 or Flood	>0.090 ft-D		<large>	Yes
(4) Area from 30.00 deg to 40.00 or Flood	>0.030 ft-D		<large>	Yes
(5) Righting Arm at 30.00 deg	>0.20 ft		<large>	Yes
(6) Absolute Angle at MaxRA	>25.00 deg	50.00	25.00	Yes
(7) GM at Equilibrium	>0.15 ft		<large>	Yes
(8) Area from 0.00 deg to MaxRA at 15.00	>0.070 ft-D	2407.474	2.941	Yes
(9) Area from 0.00 deg to MaxRA at 30.00	>0.055 ft-D	882.993	0.848	Yes



Residual Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (ft)	Residual Arm (ft)	Area (ft-Deg)	Flood Pt Height (ft)	Notes
13.10p	0.02f	38.11	-25.57	0.000	19.94 (1)	Roll
8.10p	0.01f	39.53	-17.84	-108.528	23.48 (1)	
3.10p	0.00f	39.94	-7.77	-173.553	27.54 (1)	
0.50s	0.00	39.99	0.00	-187.661	29.62 (2)	Equil
1.90s	0.00f	39.99	3.04	-185.525	28.48 (2)	
6.90s	0.01f	39.67	13.34	-144.525	24.45 (2)	
11.90s	0.02f	38.67	21.83	-55.843	20.62 (2)	
16.90s	0.01f	35.67	30.56	75.029	18.28 (2)	
21.90s	0.04f	31.47	43.05	257.494	16.87 (2)	
26.90s	0.12f	26.79	56.51	505.967	15.75 (2)	
31.90s	0.25f	22.33	67.73	817.478	14.33 (2)	
36.90s	0.43f	18.28	74.78	1175.490	12.39 (2)	
41.90s	0.63f	14.44	78.72	1560.558	10.13 (2)	
46.90s	0.85f	10.70	80.41	1959.321	7.67 (2)	
49.26s	0.95f	8.94	80.58	2149.075	6.48 (2)	MaxRa
51.90s	1.07f	6.96	80.36	2361.909	5.12 (2)	
56.90s	1.27f	2.91	78.86	2760.604	2.71 (2)	
61.90s	1.39f	-2.06	76.02	3148.362	0.90 (2)	

Note:
Residual Righting Arms shown above are in excess of the wind heeling arms derived from this moment (in ft-LT):

Stbd heeling moment = 90279.02

Roll angle is 13.43
Equilibrium for load condition without gust is 0.33s

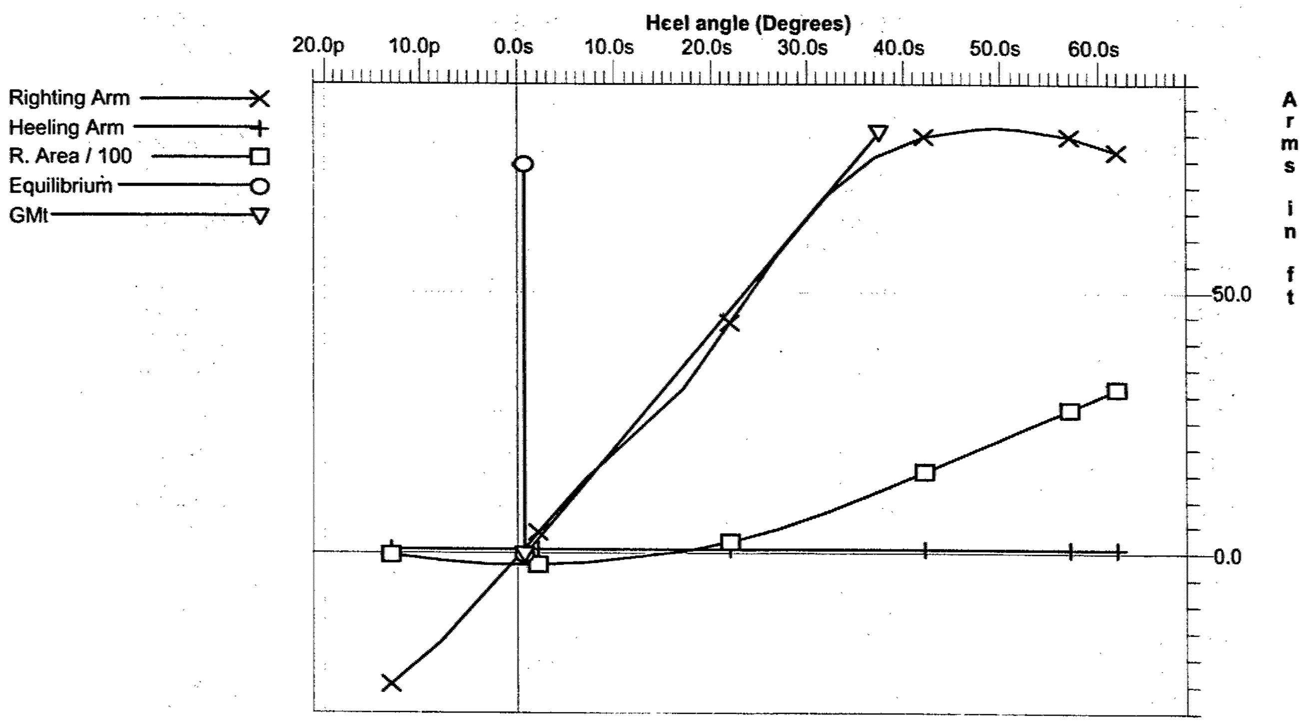
Unprotected Flood Points

Name	L,T,V (ft)	Height (ft)
(1) Engine Port Intake	230.000a, 45.000p, 70.000	19.936
(2) Engine Stbd Intake	230.000a, 45.000s, 70.000	29.617

IMO RESOLUTION A.167

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.055 ft-D		<large>	Yes
(2) Area at 30.00 deg	>0.015 ft-D		<large>	Yes
(3) Area from 0.00 deg to 40.00 or Flood	>0.090 ft-D		<large>	Yes
(4) Area from 30.00 deg to 40.00 or Flood	>0.030 ft-D		<large>	Yes
(5) Righting Arm at 30.00 deg	>0.20 ft		<large>	Yes
(6) Absolute Angle at MaxRA	>25.00 deg	49.26	24.26	Yes
(7) GM at Equilibrium	>0.15 ft		<large>	Yes
(8) Area from 0.00 deg to MaxRA at 15.00	>0.070 ft-D	2149.075	2.626	Yes
(9) Area from 0.00 deg to MaxRA at 30.00	>0.055 ft-D	75.029	0.072	Yes
(10) Abs. Area Ratio from Roll to 50.00 deg or Flood	>1.000	22.334	21.334	Yes

Righting Arms vs. Heel



APPENDIX K

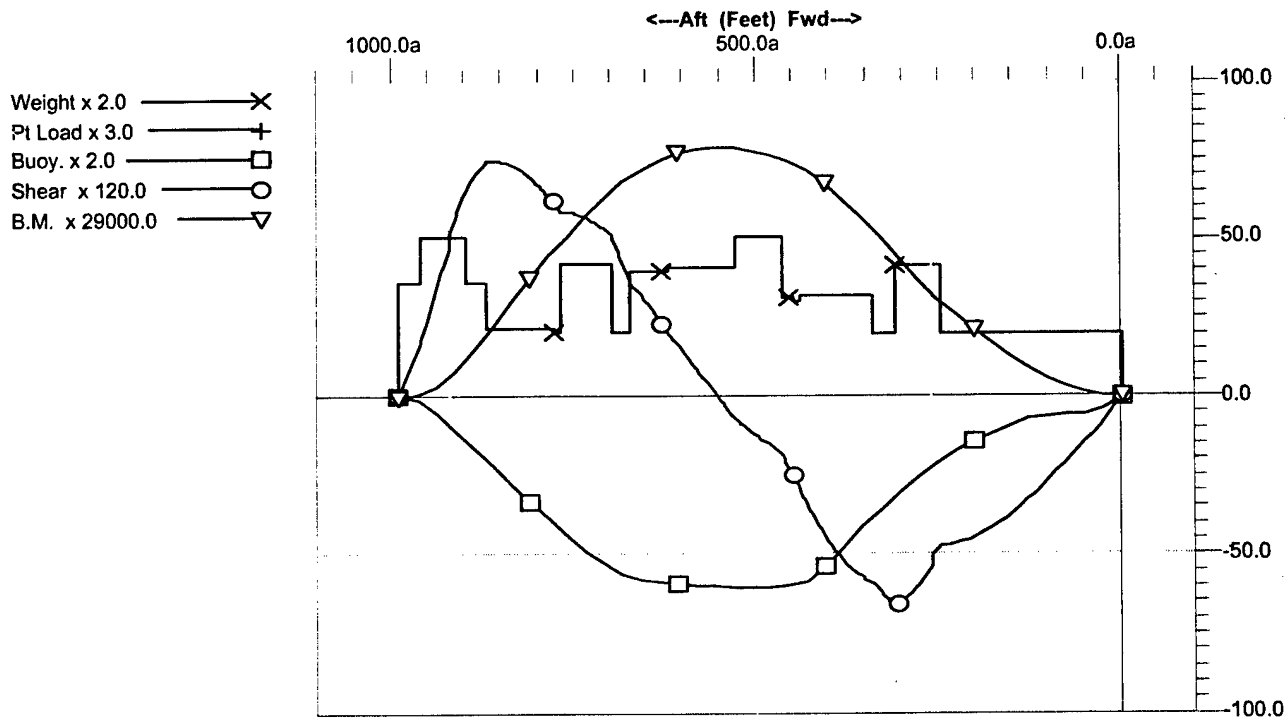
Hydrostatic and Longitudinal Strength Data

Longitudinal Strength (stbd 0.08 deg.)

Frame No.	Location (ft)	Shear (LT)	Bending (LT-ft)
COLLISION	90.000a	-2841.75	137260
FOREFUELTANK	180.000a	-4998.35	500533
ENGINE FWD	250.000a	-5627.15	881006
AMMOFWD	340.000a	-7123.39	1532942
AMMOFWD2	445.000a	-3314.91	2127145
AFTFUELTANK	530.000a	-860.59	2282230
ENGINE AFT	780.000a	7449.47	1347603

Max. Shear	8963.75 LT	at	861.980a	
Max. Bending Moment	2292626 LT-ft	at	553.980a	(Hogging)

Longitudinal Strength



Floating Status

Draft FP	41.399 ft	Heel	stbd 0.08 deg.	GM(Solid)	137.321 ft

Draft MS	35.188 ft	Equil	Yes	F/S Corr.	0.000 ft
Draft AP	28.977 ft	Wind	0.0 kn	GM(Fluid)	137.321 ft
Trim	fwd 0.72 deg.	Wave	No	KMT	181.785 ft
LCG	543.848a ft	VCG	44.475 ft	TPIn	223.31

Loading Summary

Item	Weight (LT)	LCG (ft)	TCG (ft)	VCG (ft)
Light Ship	39,996.00	495.000a	0.000	40.000
Deadweight	25,301.30	621.067a	0.473s	51.549
Displacement	65,297.30	543.848a	0.183s	44.475

Fixed Weight Status

Item	Weight (LT)	LCG (ft)	TCG (ft)	VCG (ft)
LIGHT SHIP	39,996.00	495.000a	0.000	40.000u
CREW BERTHING	358.80	875.000a	0.000	95.000u
HANGARDECK	499.20	600.000a	0.000	90.000u
LCUDECKPORT	221.00	535.000a	90.000p	90.000u
LCUDECKSTBD	221.00	535.000a	90.000s	90.000u
MAGAZINE1&2	3,496.00	435.000a	0.000	20.000u
PROPULSIONMR1	2,999.50	735.000a	30.000s	20.000u
PROPULSIONMR2	2,598.00	280.000a	0.000	20.000u
PROPULSIONMR3	2,601.00	945.000a	30.000p	90.000u
RAILGUNPORTAFT	210.00	920.000a	110.000p	90.000u
RAILGUNPORTFWD	210.00	260.000a	70.000p	90.000u
RAILGUNSTBDAFT	210.00	920.000a	110.000s	90.000u
RAILGUNSTBDFWD	210.00	260.000a	70.000s	90.000u
THRUSTERRM	2,529.00	915.000a	0.000	90.000u
VEHICLEDECK1	3,998.40	570.000a	0.000	60.000u
VEHICLEDECK2	3,998.40	570.000a	0.000	40.000u
WAREHOUSE	500.00	390.000a	0.000	80.000u
WELLDECKLCAC	441.00	885.000a	0.000	60.000u
Total Weight:	**65,297.30**	**543.848a**	**0.183s**	**44.475u**

Displacer Status

Item	Status	Spgr	Displ (LT)	LCB (ft)	TCB (ft)	VCB (ft)	Eff /Perm
HULL1	Intact	1.025	65,297.51	543.545a	0.215s	20.239	0.992
SubTotals:			**65,297.51**	**543.545a**	**0.215s**	**20.239**	

Righting Arms vs Heel Angle

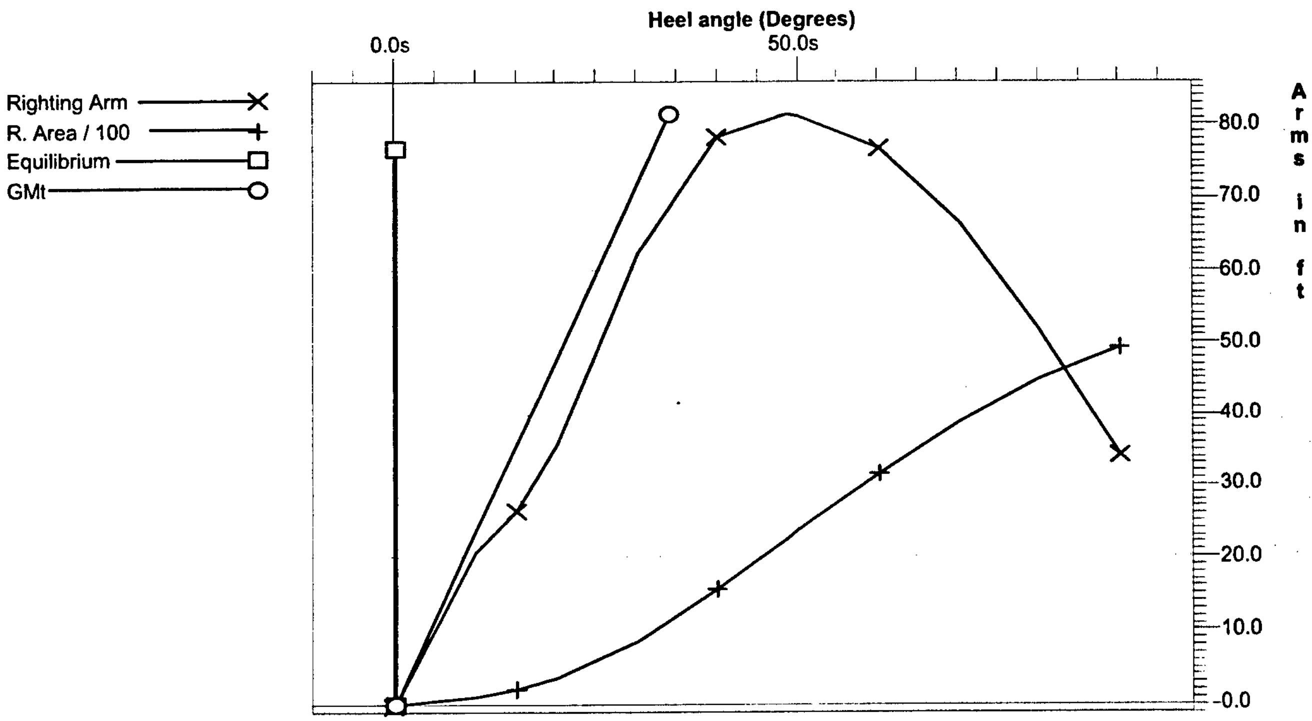
Heel Angle (deg)	Trim Angle (deg)	Origin Depth (ft)	Righting Arm (ft)	Area (ft-Deg)	Notes
0.00	**0.72f**	**41.40**	**-0.18**	**0.000**	
0.08s	**0.72f**	**41.41**	**0.00**	**-0.007**	**Equil**
10.00s	**0.78f**	**40.63**	**20.63**	**102.345**	
15.00s	**0.81f**	**38.83**	**26.45**	**221.319**	

20.00s	0.79f	35.40	35.74	375.370	
30.00s	1.01f	26.90	62.60	857.866	
40.00s	1.61f	20.05	78.41	1572.091	
48.53s	2.27f	15.25	81.47	2260.611	MaxRa
50.00s	2.39f	14.49	81.37	2380.454	
60.00s	3.30f	9.77	76.89	3177.953	
70.00s	4.28f	4.83	66.64	3900.407	
80.00s	5.15f	-1.65	51.96	4497.071	
90.00s	5.70f	-11.19	34.32	4930.910	

IMO RESOLUTION A.167

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.055 ft-D		<large>	Yes
(2) Area at 30.00 deg	>0.015 ft-D		<large>	Yes
(3) Area from 0.00 deg to 40.00 or Flood	>0.090 ft-D		<large>	Yes
(4) Area from 30.00 deg to 40.00 or Flood	>0.030 ft-D		<large>	Yes
(5) Righting Arm at 30.00 deg	>0.20 ft		<large>	Yes
(6) Absolute Angle at MaxRA	>25.00 deg	48.53	23.53	Yes
(7) GM at Equilibrium	>0.15 ft		<large>	Yes
(8) Area from 0.00 deg to MaxRA at 15.00	>0.070 ft-D	2260.611	2.762	Yes
(9) Area from 0.00 deg to MaxRA at 30.00	>0.055 ft-D	857.867	0.823	Yes

Righting Arms vs. Heel



Floating Status

Draft FP	41.399 ft	Heel	stbd 0.08 deg.	GM(Solid)	137.321 ft
Draft MS	35.188 ft	Equil	No	F/S Corr.	0.000 ft
Draft AP	28.977 ft	Wind	0.0 kn	GM(Fluid)	137.321 ft
Trim	fwd 0.72 deg.	Wave	No	KMT	181.785 ft
LCG	543.848a ft	VCG	44.475 ft	TPIn	223.31

Loading Summary

Item	Weight (LT)	LCG (ft)	TCG (ft)	VCG (ft)
Light Ship	39,996.00	495.000a	0.000	40.000
Deadweight	25,301.30	621.067a	0.473s	51.549
Displacement	65,297.30	543.848a	0.183s	44.475

Fixed Weight Status

Item	Weight (LT)	LCG (ft)	TCG (ft)	VCG (ft)
LIGHT SHIP	39,996.00	495.000a	0.000	40.000u
CREW BERTHING	358.80	875.000a	0.000	95.000u
HANGARDECK	499.20	600.000a	0.000	90.000u
LCUDECKPORT	221.00	535.000a	90.000p	90.000u
LCUDECKSTBD	221.00	535.000a	90.000s	90.000u
MAGAZINE1&2	3,496.00	435.000a	0.000	20.000u
PROPULSIONMR1	2,999.50	735.000a	30.000s	20.000u
PROPULSIONMR2	2,598.00	280.000a	0.000	20.000u
PROPULSIONMR3	2,601.00	945.000a	30.000p	90.000u
RAILGUNPORTAFT	210.00	920.000a	110.000p	90.000u
RAILGUNPORTFWD	210.00	260.000a	70.000p	90.000u
RAILGUNSTBDAFT	210.00	920.000a	110.000s	90.000u
RAILGUNSTBDFWD	210.00	260.000a	70.000s	90.000u
THRUSTERRM	2,529.00	915.000a	0.000	90.000u
VEHICLEDECK1	3,998.40	570.000a	0.000	60.000u
VEHICLEDECK2	3,998.40	570.000a	0.000	40.000u
WAREHOUSE	500.00	390.000a	0.000	80.000u
WELLDECKLCAC	441.00	885.000a	0.000	60.000u
Total Weight:	65,297.30	543.848a	0.183s	44.475u

Displacer Status

Item	Status	Spgr	Displ (LT)	LCB (ft)	TCB (ft)	VCB (ft)	Eff /Perm
HULL1	Intact	1.025	65,297.51	543.545a	0.215s	20.239	0.992
SubTotals:			65,297.51	543.545a	0.215s	20.239	

Heeling Moment Derivation

Wind Velocity at 10 meters = 100.0 knots from port, CD= 1.200

Part	LPA (ft^2)	HCP (ft)	Arm (ft)	Pressure (LT/ft^2)	Moment (ft-LT)
MIANHULL	81352	30.52	45.25	0.018	67289.790

Residual Righting Arms vs Heel Angle

Heel Angle (deg)	Trim Angle (deg)	Origin Depth (ft)	Residual Arm (ft)	Area (ft-Deg)	Flood Pt Height (ft)	Notes
15.10p	0.81f	38.78	-28.38	0.000	20.31 (1)	Roll
10.10p	0.78f	40.60	-22.59	-127.421	23.55 (1)	
5.10p	0.74f	41.27	-13.66	-219.359	27.41 (1)	
0.10p	0.72f	41.41	-1.96	-259.571	31.40 (1)	
0.72s	0.72f	41.41	0.00	-260.367	30.91 (2)	Equil
4.90s	0.73f	41.28	9.81	-239.823	27.56 (2)	
9.90s	0.78f	40.65	19.02	-167.061	23.67 (2)	
14.90s	0.81f	38.88	24.88	-55.912	20.42 (2)	
19.90s	0.79f	35.48	34.15	90.250	18.18 (2)	
24.90s	0.85f	31.31	47.39	292.432	16.63 (2)	
29.90s	1.00f	26.98	61.20	563.649	15.28 (2)	
34.90s	1.28f	23.34	71.47	896.791	13.44 (2)	
39.90s	1.61f	20.13	77.39	1270.764	11.14 (2)	
44.90s	1.98f	17.21	80.21	1666.053	8.52 (2)	
48.57s	2.27f	15.22	80.82	1961.943	6.47 (2)	MaxRa
49.90s	2.38f	14.54	80.74	2069.356	5.67 (2)	
54.90s	2.82f	12.11	79.44	2470.622	2.65 (2)	
59.21s	3.23f	10.14	77.07	2807.608	0.00 (2)	FldPt
59.90s	3.29f	9.82	76.58	2861.303	-0.43 (2)	

Note:
Residual Righting Arms shown above are in excess of the wind heeling arms derived from these moments (in ft-LT):
Stbd heeling moment = 1.01E+05Cos^2(heel) + 0.00

Roll angle is 15.60
Equilibrium for load condition without gust is 0.50s

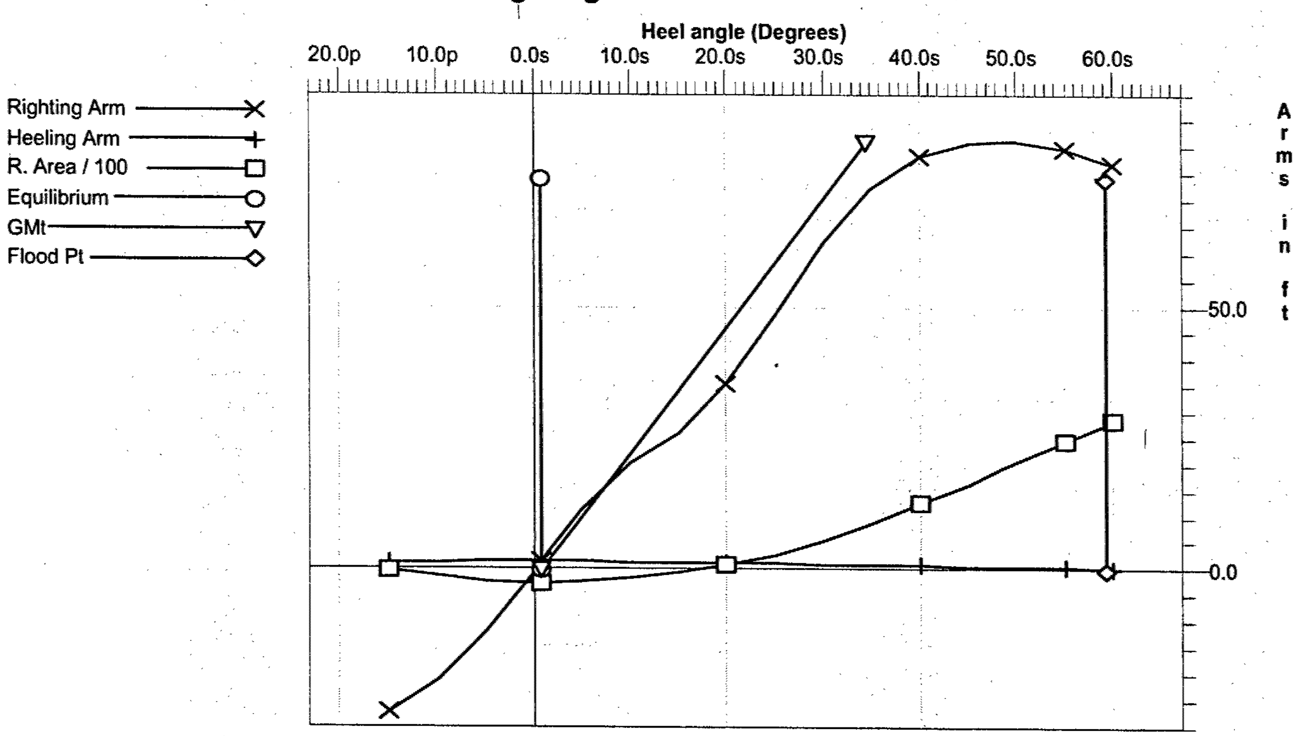
Unprotected Flood Points

Name	L,T,V (ft)	Height (ft)
(1) Engine Port Intake	230.000a, 45.000p, 70.000	20.313
(2) Engine Stbd Intake	230.000a, 45.000s, 70.000	30.909

IMO RESOLUTION A.167

Limit	Min/Max	Actual	Margin	Pass
(1) Area from 0.00 deg to 30.00	>0.055 ft-D		<und>	No
(2) Area at 30.00 deg	>0.015 ft-D		<und>	No
(3) Area from 0.00 deg to 40.00 or Flood	>0.090 ft-D		<large>	Yes
(4) Area from 30.00 deg to 40.00 or Flood	>0.030 ft-D		<large>	Yes
(5) Righting Arm at 30.00 deg	>0.20 ft		<large>	Yes
(6) Absolute Angle at MaxRA	>25.00 deg	48.57	23.57	Yes
(7) GM at Equilibrium	>0.15 ft		<large>	Yes
(8) Area from 0.00 deg to MaxRA at 15.00	>0.070 ft-D	1961.943	2.397	Yes
(9) Area from 0.00 deg to MaxRA at 30.00	>0.055 ft-D	-55.912	0.054	No
(10) Abs. Area Ratio from Roll to 50.00 deg or Flood	>1.000	13.716	12.716	Yes

Righting Arms vs. Heel



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